New Thermal Governor Model Selection and Validation in the WECC

Presentation at MVWG 2006 Workshop

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Governor Modeling Task Force Members

- Les Pereira, Chair GMTF, Past Chair MVWG
- John Undrill
- Dmitry Kosterev, Chair LMTF
- Donald Davies, Chair MDTF
- Shawn Patterson, Past Chair MVWG
- Mark Willis

New Thermal Governor Model Selection and Validation in the WECC – IEEE Trans. Papers

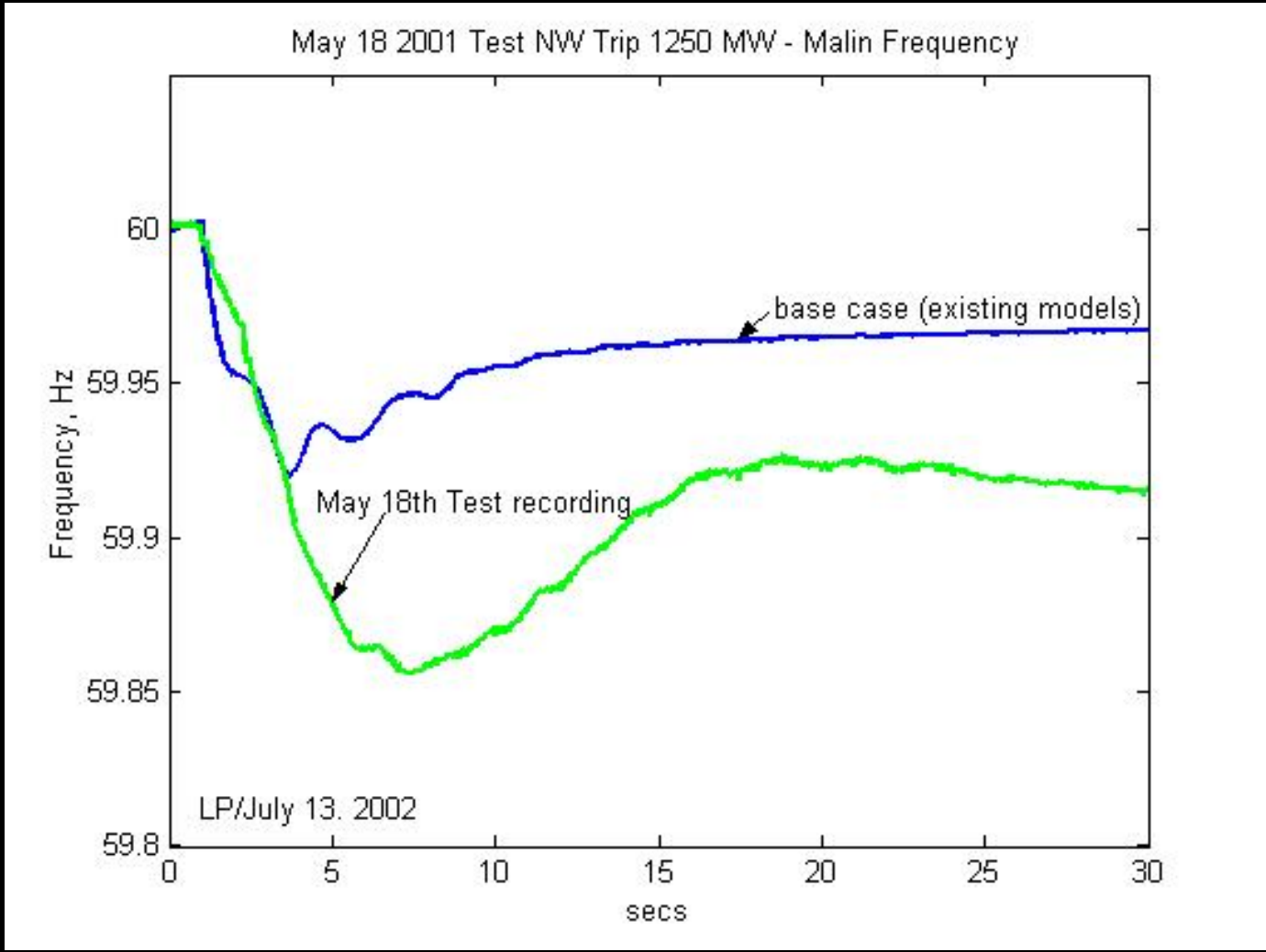
1. "A New Thermal Governor Modeling Approach in the WECC"

   by L. Pereira, J. Undrill, D. Kosterev, D. Davies, S. Patterson, *IEEE Trans. Power Systems*, vol. 18, Issue.2, pp. 819-829, May 2003. (*IEEE 2004 prize paper). Presented at Toronto IEEE PES, July 2003.*

2. "New Thermal Governor Model Selection and Validation in the WECC"

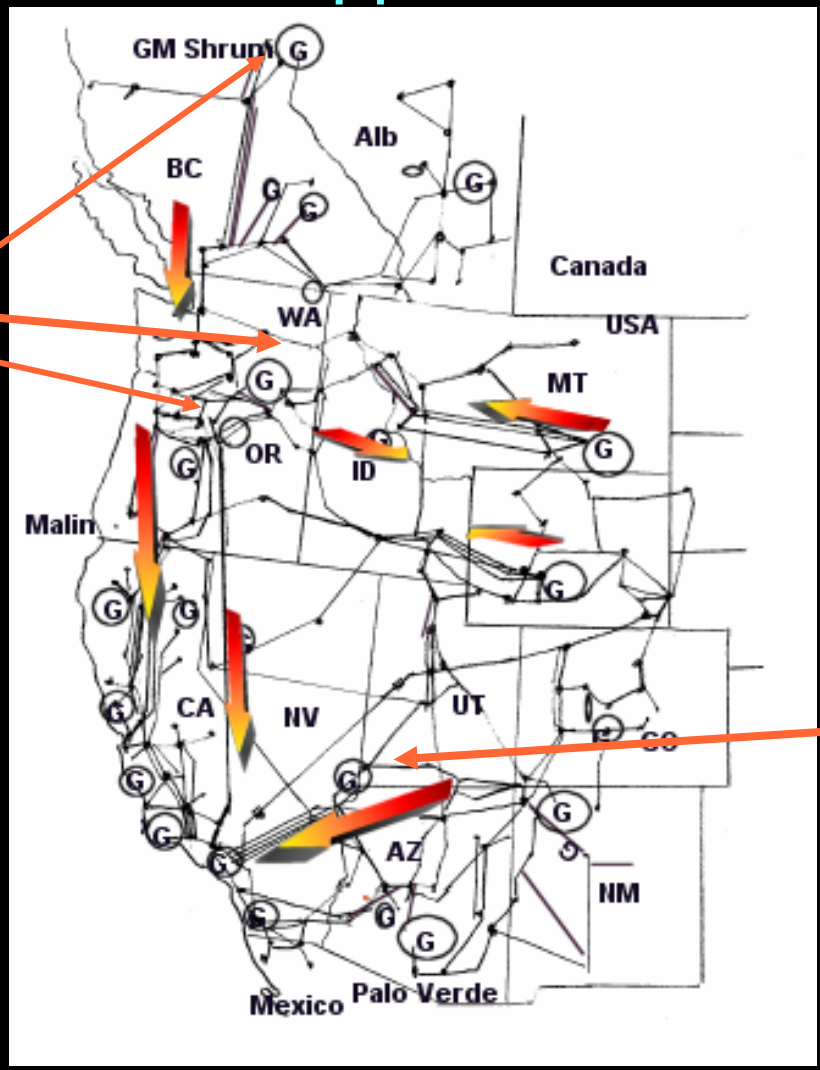
   by Les Pereira, Dmitry Kosterev, Donald Davies, and Shawn Patterson - IEEE TPWRS – Vol.19, No.1, pp 517-523, February 2004. *Presented at Denver IEEE PES, July 2004.*

Discrepancy between recording Vs existing (old) governor frequency modeling



May 18th 2001 Tests – Tripped 750 MW in SW and 20 min later – Tripped 1250 MW in NW

1250 MW
NW Trip
Test No.2

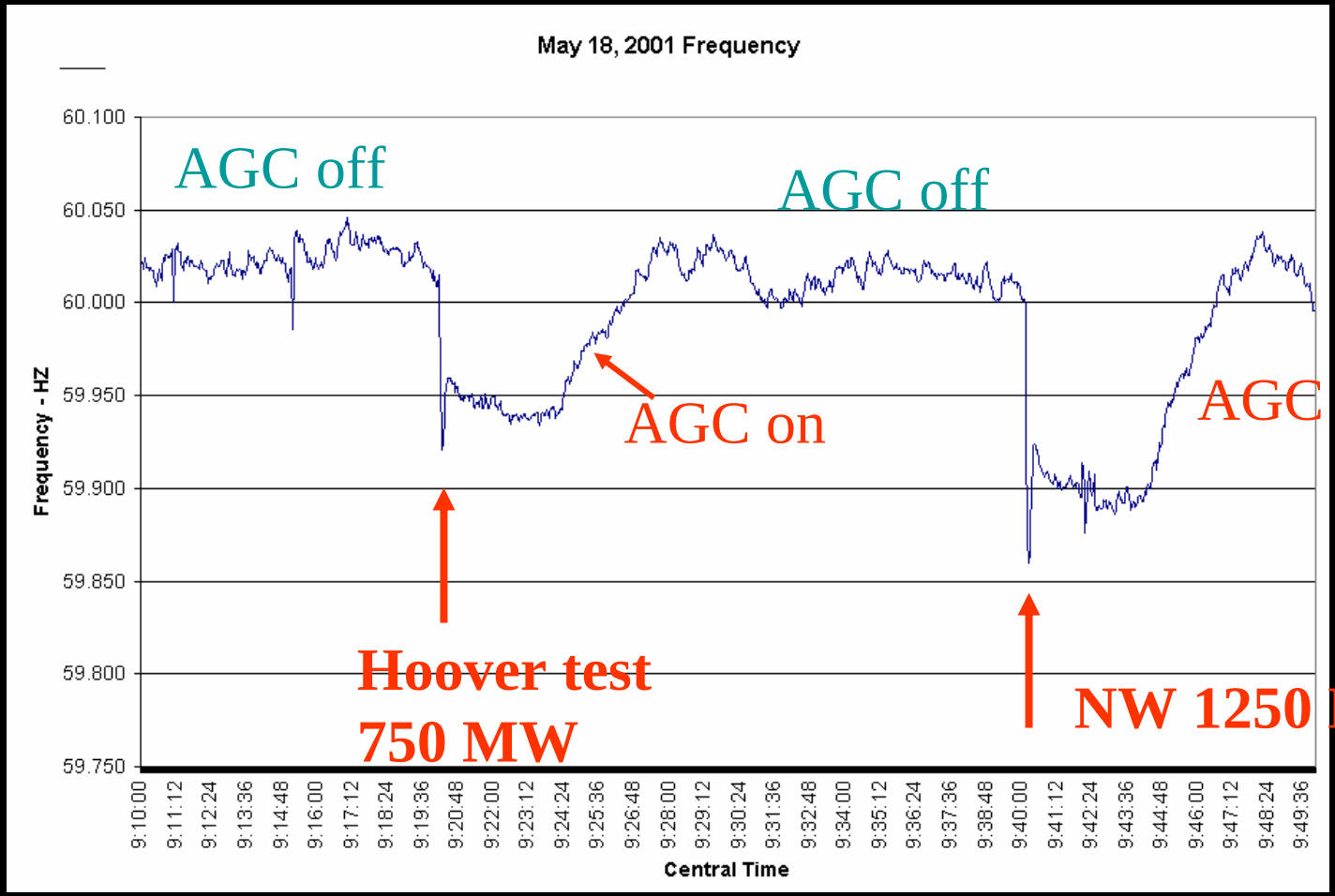


750 MW in SW
Test No. 1

AGC was switched off

- AGC was switched off during each test throughout the WECC
- Pickup of generation in the system was therefore entirely due to governor action

Frequency Plots - Hoover & NW Trips- May 18, 2001



Test Recordings taken throughout WECC

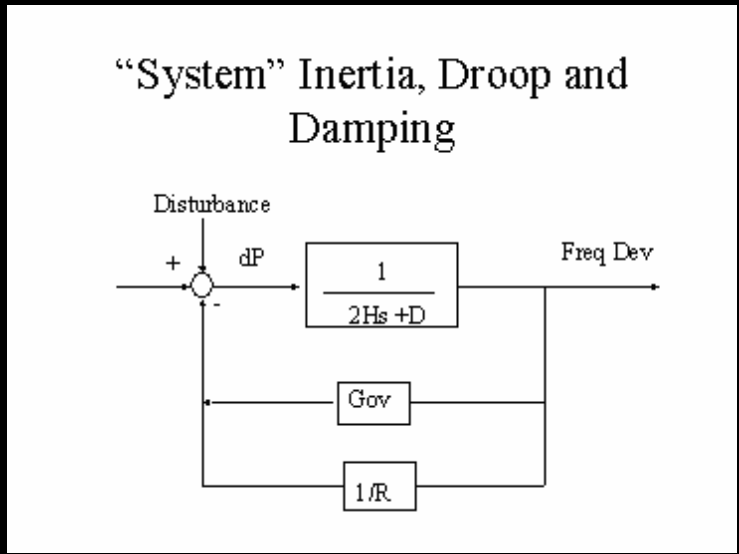
- Disturbance monitoring at BPA, SCE etc
- SCADA recordings at all Control Areas

- Calculations showed that governor response was only 40% of expected 5% droop response

Generators pick-up according to their size and the level of freq deviation - typical calculation

- Frequency deviation in system = 0.1 Hz
- Governor Droop = 5%
- 100 MW rated Generator pickup = $\frac{(0.1/60) \times 100 \text{ MW}}{0.05}$ = 3.3 MW

$$\frac{\Delta\omega}{\Delta P} := \frac{1}{\left(\frac{1}{R} + D\right)}$$



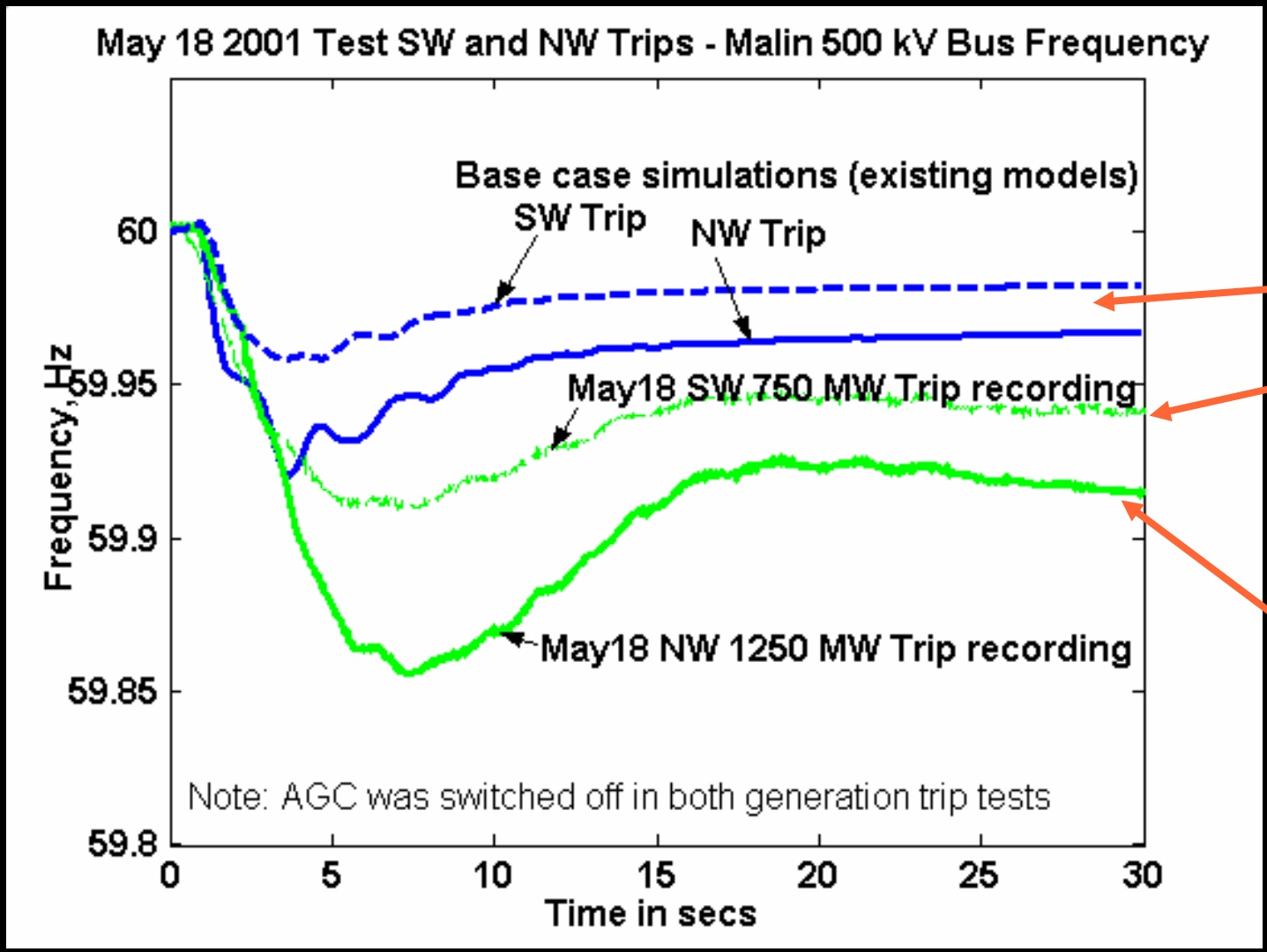
Approximate Generator Response Calculations

- Generation tripped May 18th = 1250 MW
- WECC generation = 91,000 MW
- Settling frequency = 0.105 Hz
- Calculated Generation pickup = 3185 MW
- But the actual pickup was only = 1250 MW.
- Percentage of responsive governors with a 5% droop =

  = (1250/3185) = 39%

  - Note: Simplistic calculation
  - Load damping and the effect of redistributed losses are neglected

Frequency simulations with the old model compared with recordings were clearly incorrect by a wide margin!



Old model simulations

750 MW actual recording

1250 MW actual recording

The Unresponsive Units?

- Largely the Thermal Units (steam, nuclear steam, gas turbines)
  - Base-loaded units - fixed valve opening
  - Units at load limits (Eg. temperature limits of gas turbines)
  - Units with MW Load Controllers

- The Responsive Units? Hydro and some thermals

Note: Hydro plants on water management can be considered “base” load plants too

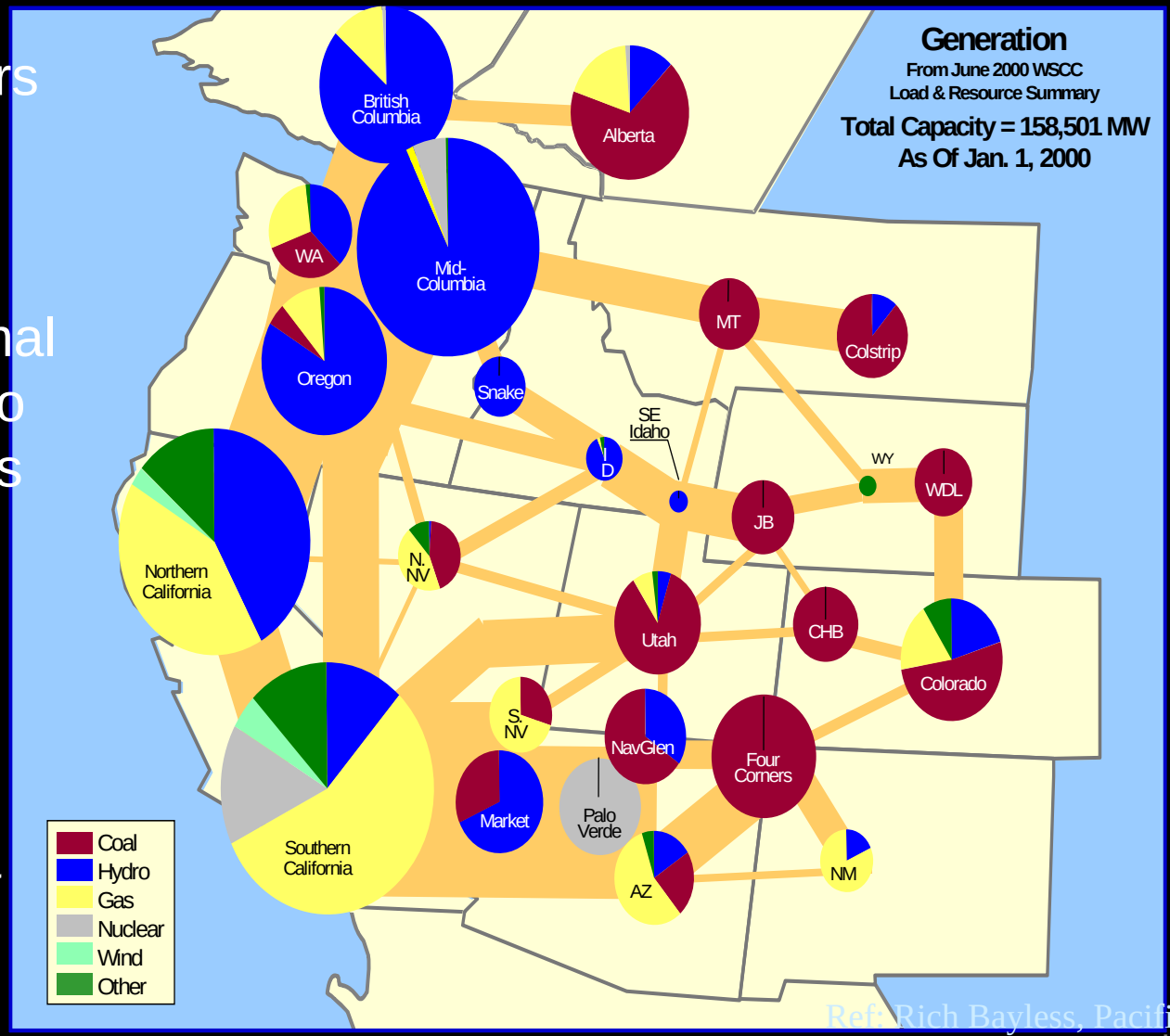
Hydro in NW – and Thermals in S-SW

- 2600 generators modeled

Summer peak

- 145,000 MW
- 55 -65% thermal
- 35 - 45% hydro
- 600 generators baseloaded = 67,000 MW

- 7000 loads
- 13,500 buses
- 12,200 lines & transformers

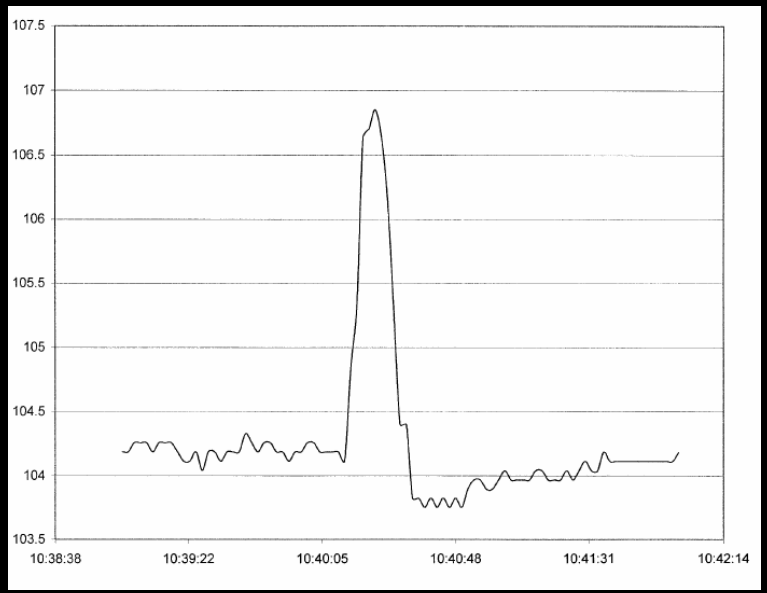


Ref: Rich Bayless, Pacific Corp

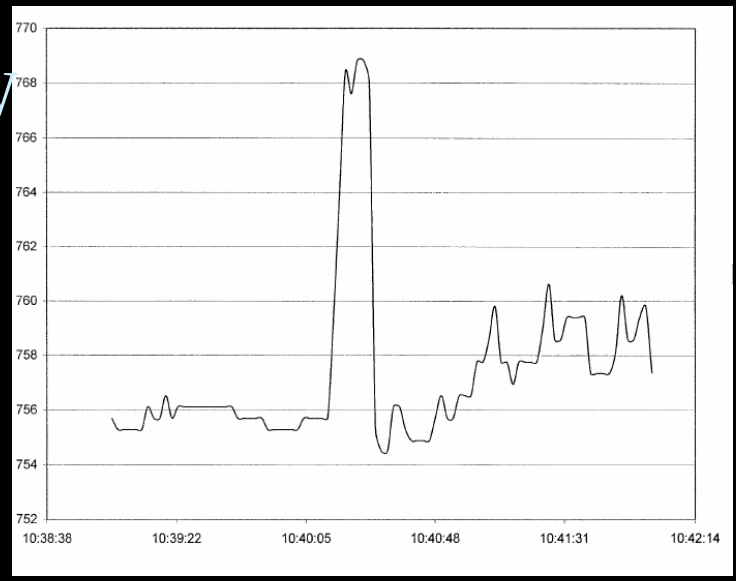
SCADA plots of the generator are electrical responses

- SCADA plots are “approximate envelopes” because of 2 second or 4 second interval plotting
- All transient peaks will not be captured
- The first peak is typically “inertial” -electrical and is not a ‘governor’ mechanical MW response

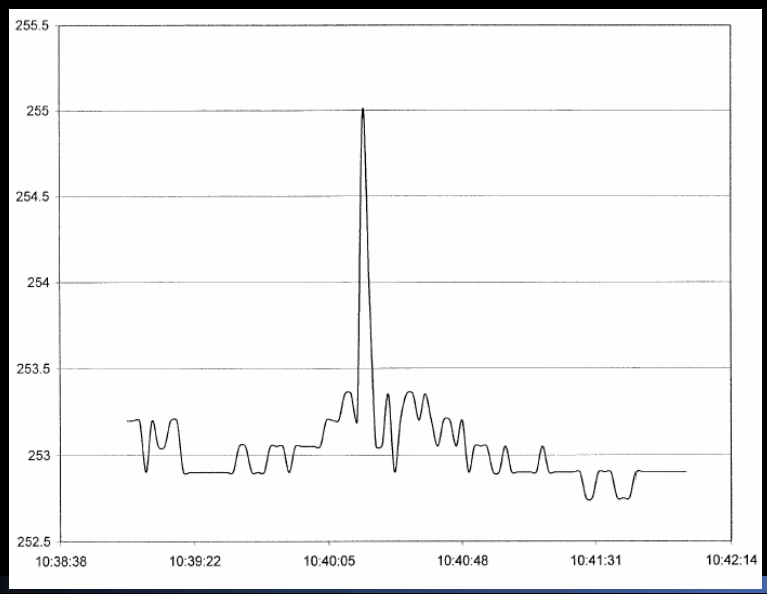
“Base Loaded” units - SCADA recordings



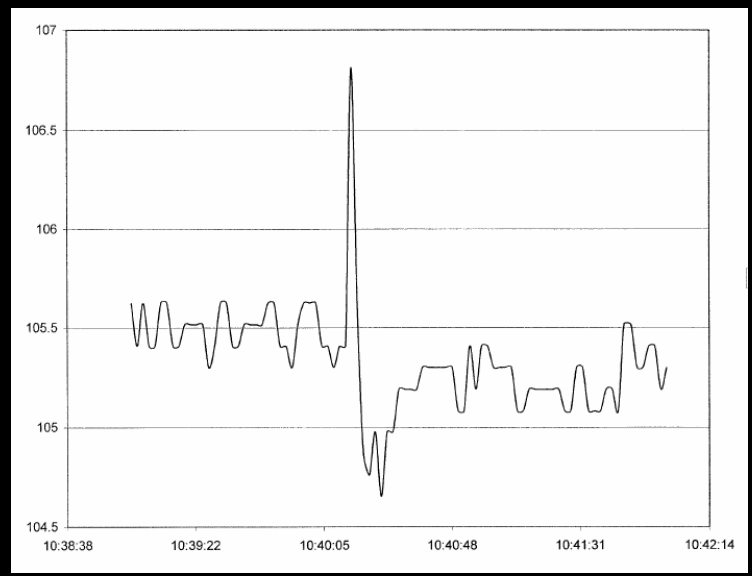
107 MW



770

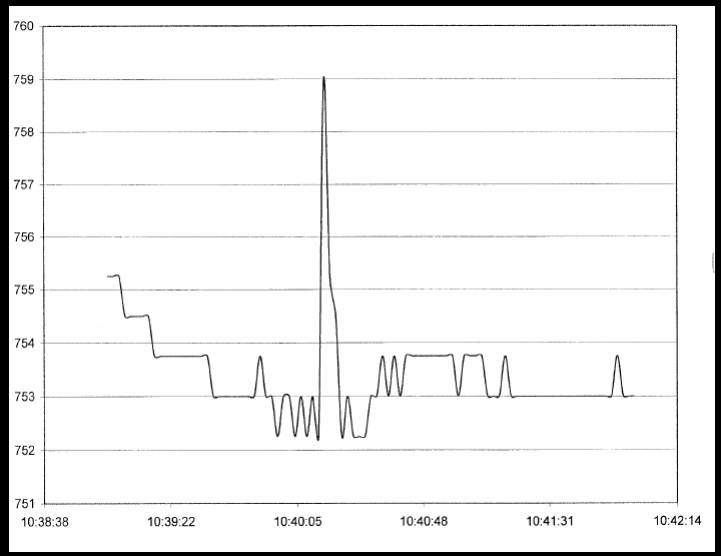


255



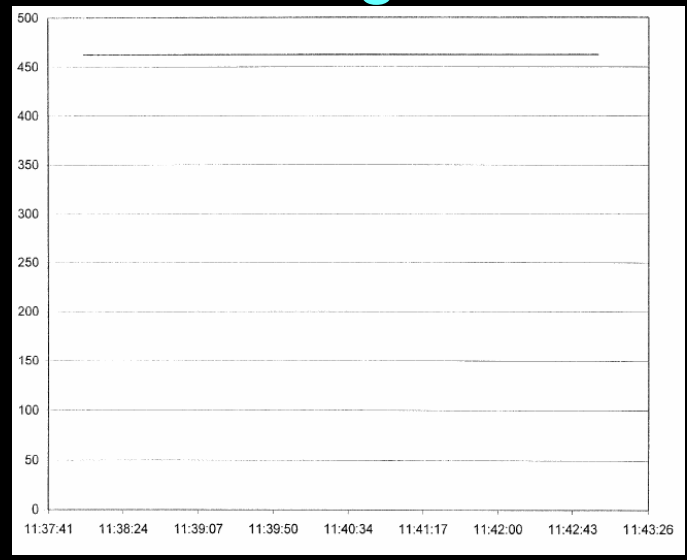
107

“Base Loaded” units - SCADA recordings



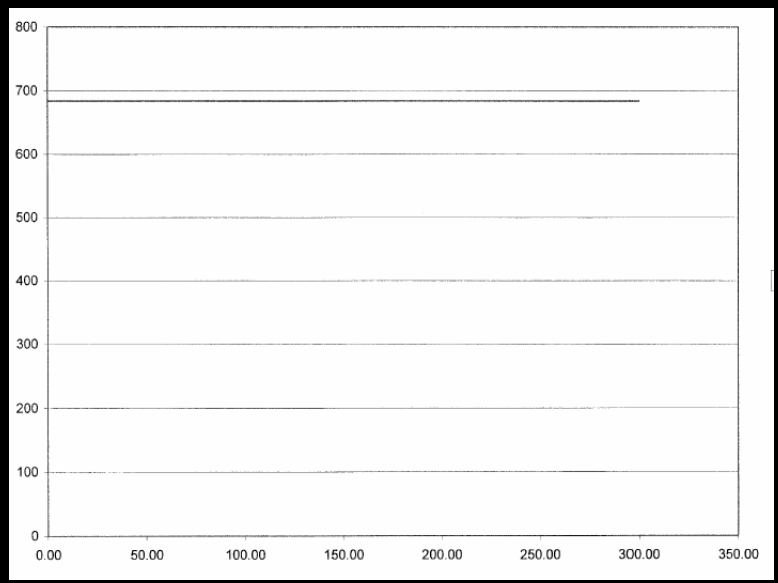
760

750



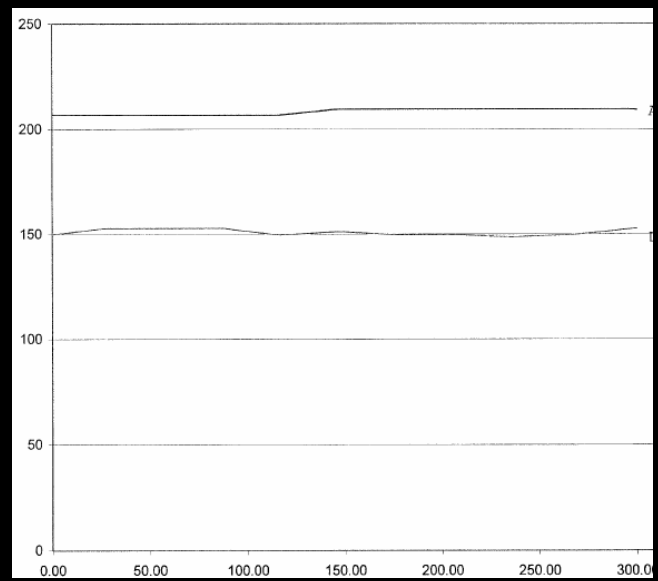
500

0



800

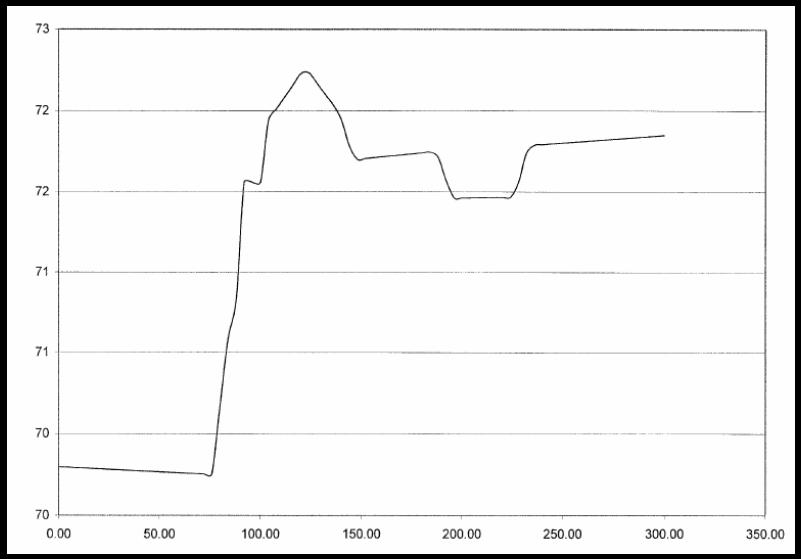
0



250

0

“Fully Responsive” SCADA recordings



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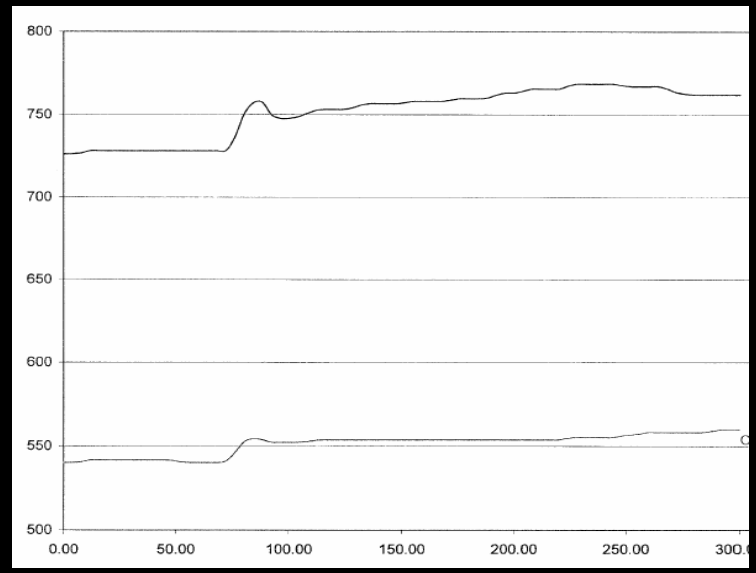
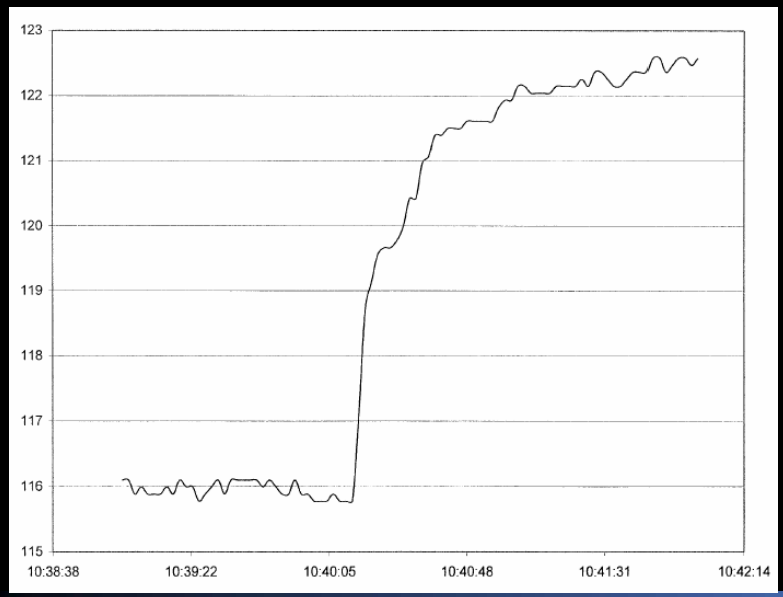


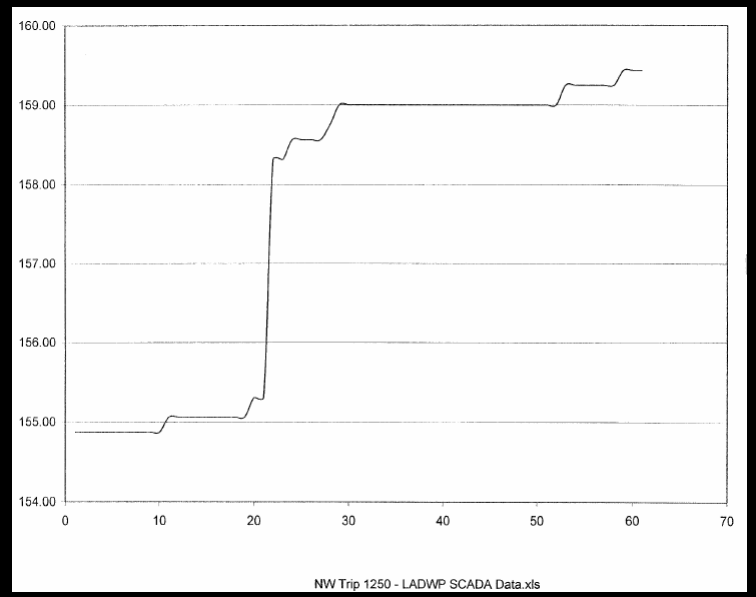
800

500



123

115

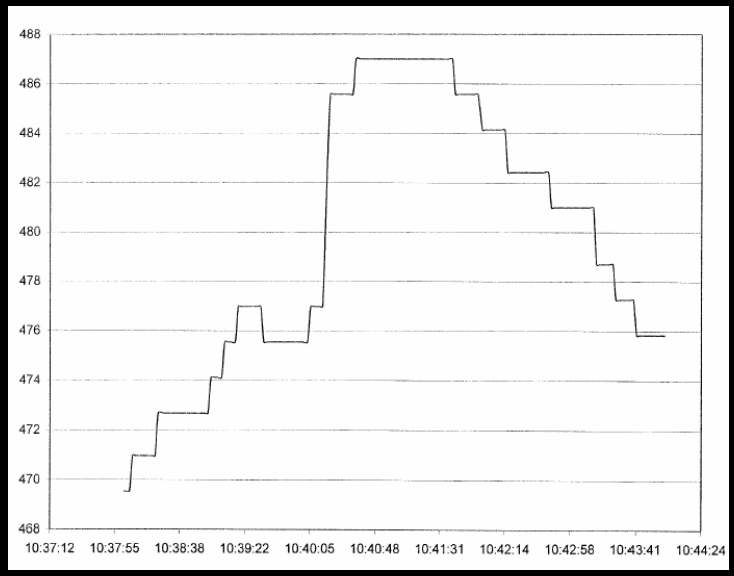


160

154

Load controllers or run-back - SCADA recordings

488



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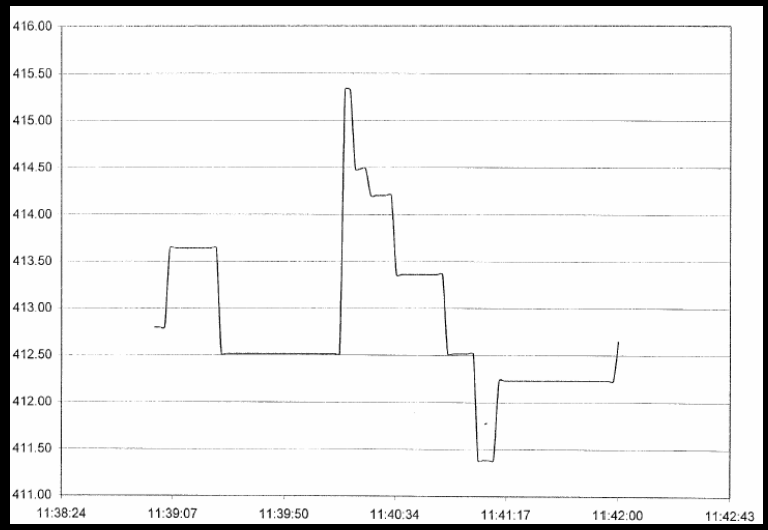

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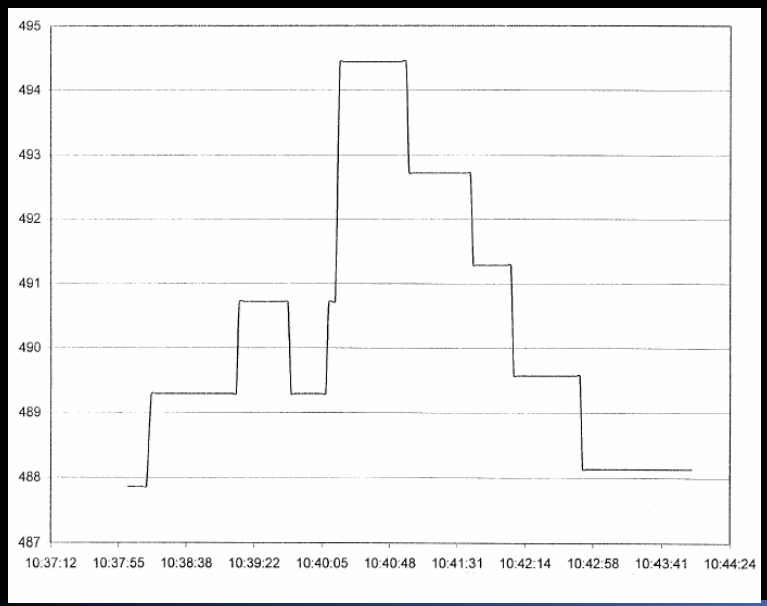

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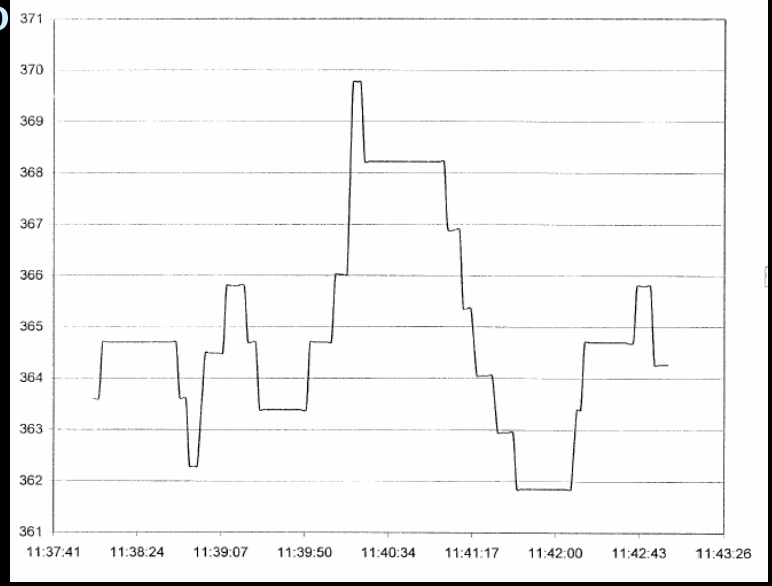
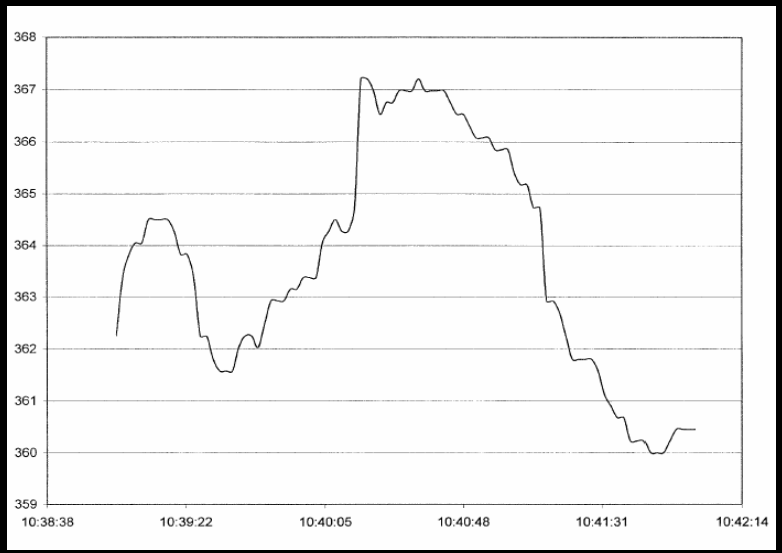


Load controllers /run-back - SCADA recordings



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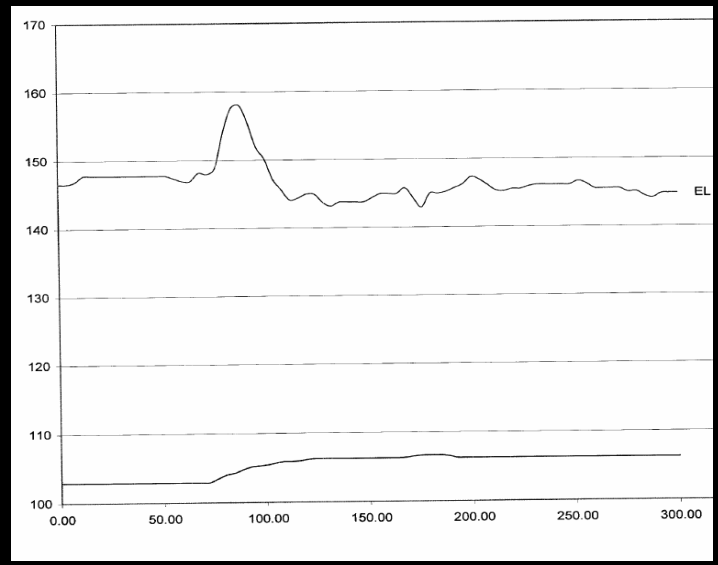
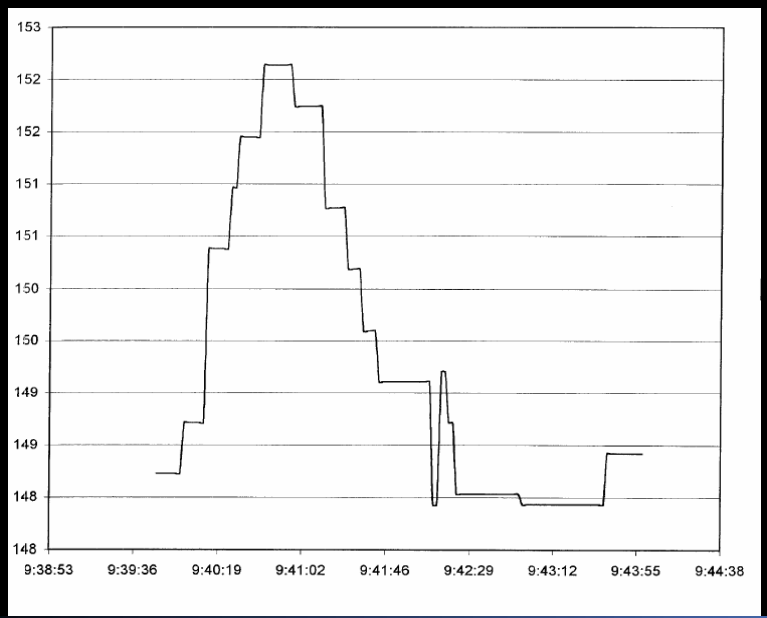


170

100



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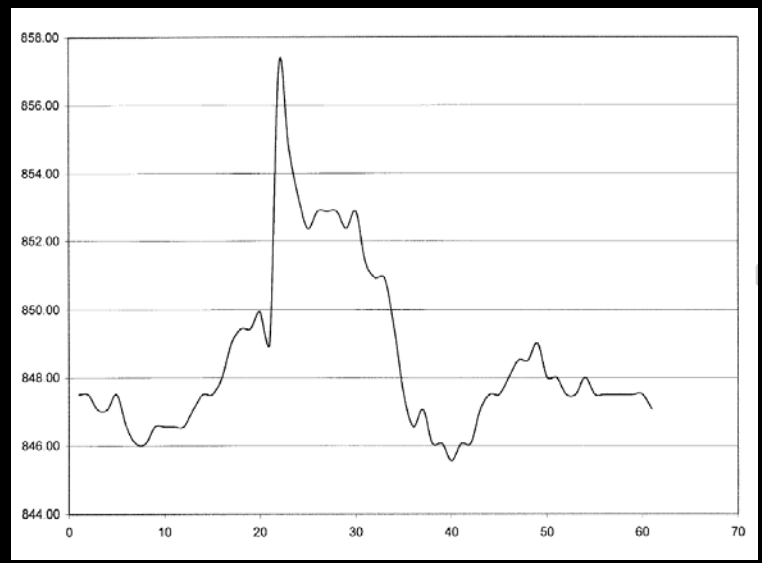


858

May 18th 2001 Test Disturbance Monitoring and SCADA Plots

- Total units (thermal and hydro)
  - Over 1500 units
  - Approx 1100 units were thermal
  - 91,000 MW

‘Base’ Load Units

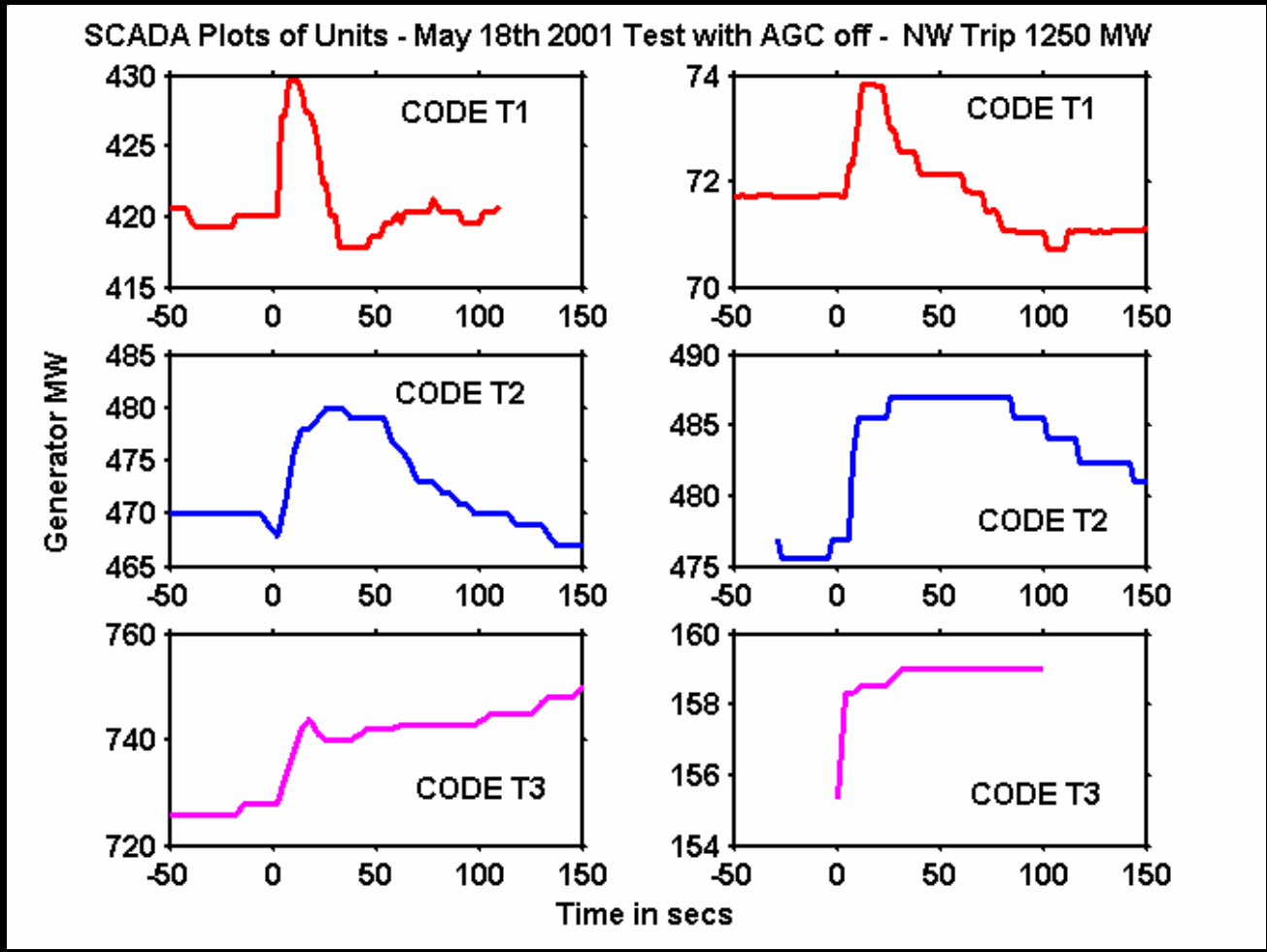
- Base loaded units were identified by a Base Load Flag in the power flow data
- GE PSLF and PTI PSSE does it. Do other powerflow programs do it?

MW Controller Codes were classified:

- Codes Thermal : T1, T2, T3
  - - T1 = Fast Controller
  - - T2 = Slow Controller
  - - T3 = No Controller
- Codes Gas : G1, G2

  - Fast Controller

Classification- Coded T1 to T3, and Base Loaded



Turbine codes and typical data

Table 1 Principal Parameters of the New Thermal Turbine-Governor Model ggov1 for the various designated Codes.

					P	I	D	
Code		r	Tb	Tc	Kpgov	Kigov	Kdgov	Kimw
T1	Fast load controller	.05	10	2	10	2	0	0.01 to 0.02
T2	Slow load controller	.05	10	2	10	2	0	0.001 to 0.005
T3	No load controller	.05	10	2	10	2	0	0
G1	With load controller	.05	0.5	0	10	2	0	0.01 to 0.02
G2	No load controller	.05	0.5	0	10	2	0	0

The principal parameters of the model are:

r	Permanent Speed Droop, pu
Tb	Turbine lag time constant, secs
Tc	Turbine lead time constant, secs
Kpgov	Governor proportional gain, pu
Kigov	Governor integral gain, pu
Kdgov	Governor derivative gain, pu
Kimw	Load (power) controller gain, pu

GE PSLF ggov1 model

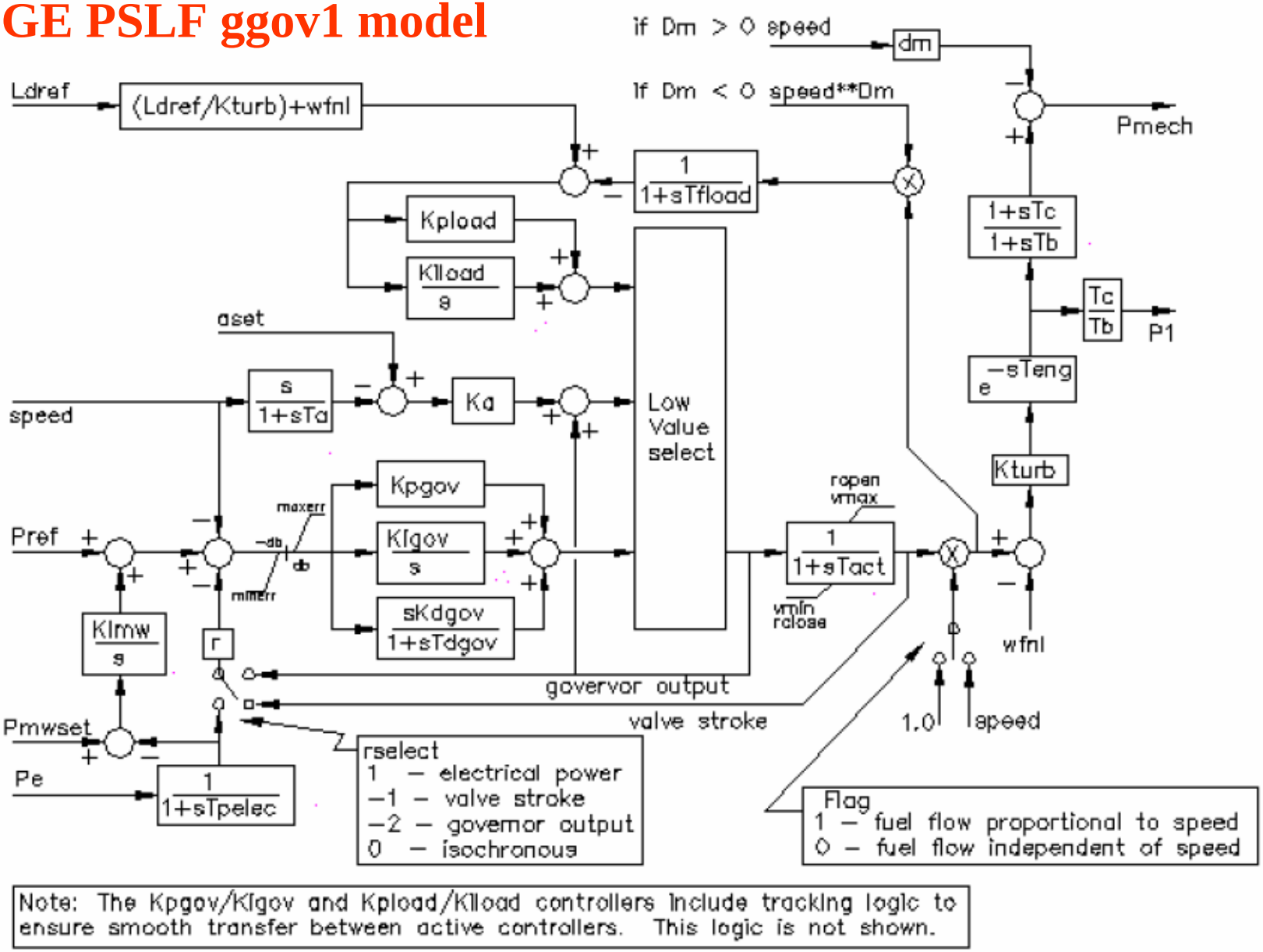
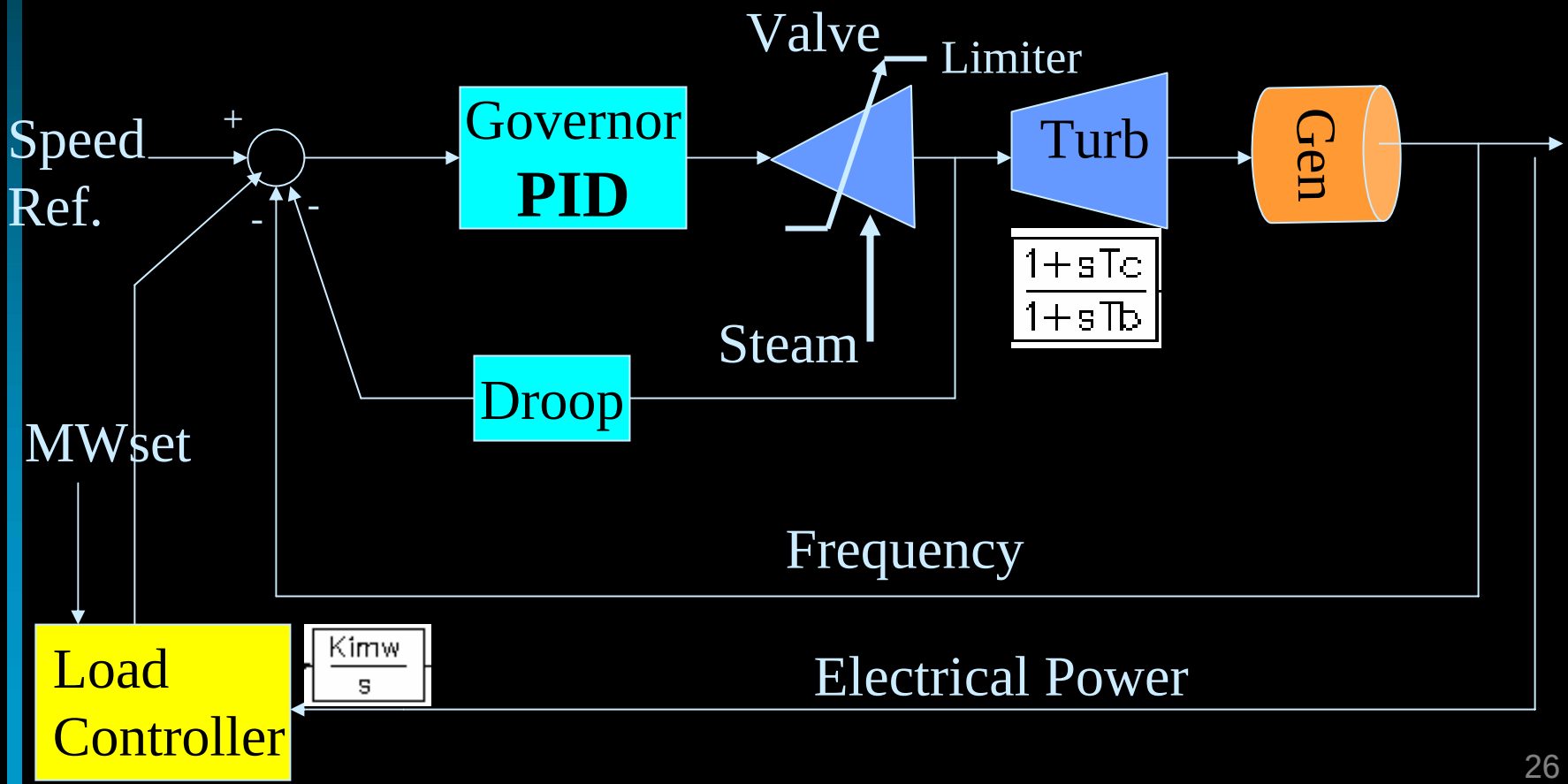


Fig. A1 Block diagram showing the basic relationships of the turbine-governor plant model ggov1 [8]

Governor Block Diagram with Load Controller and Limiter



Computer Simulations with the "New" Turbine Governor "Codes"

MAY 18TH 2001 TEST

1250 MW TRIPPED IN THE NW

AGC OFF

All the plots in this presentation are color coded as follows:

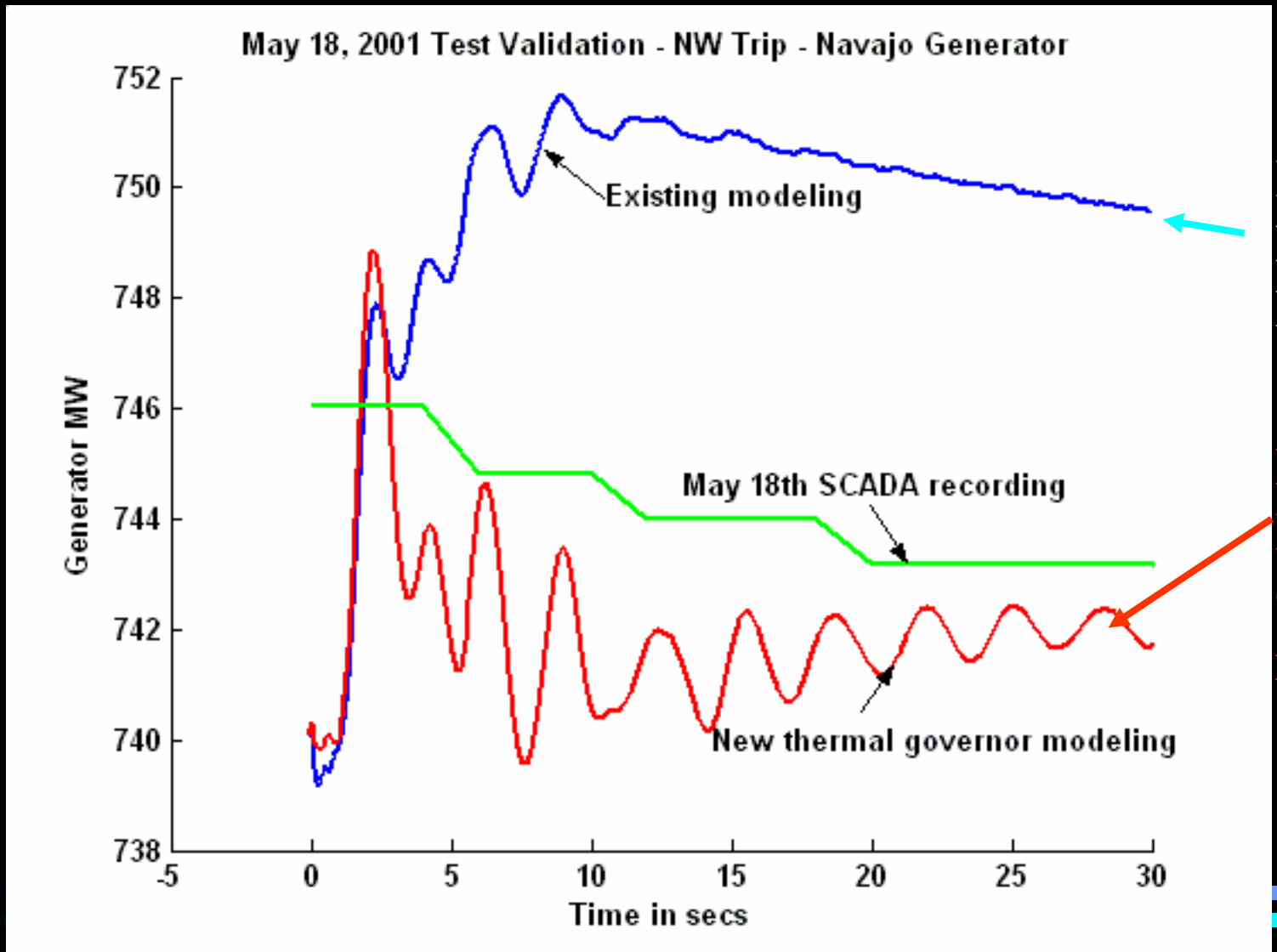
Blue - Existing Model

Red – New Governor Model

Green – Actual event recording

Note: SCADA plots are an approximate “envelope”

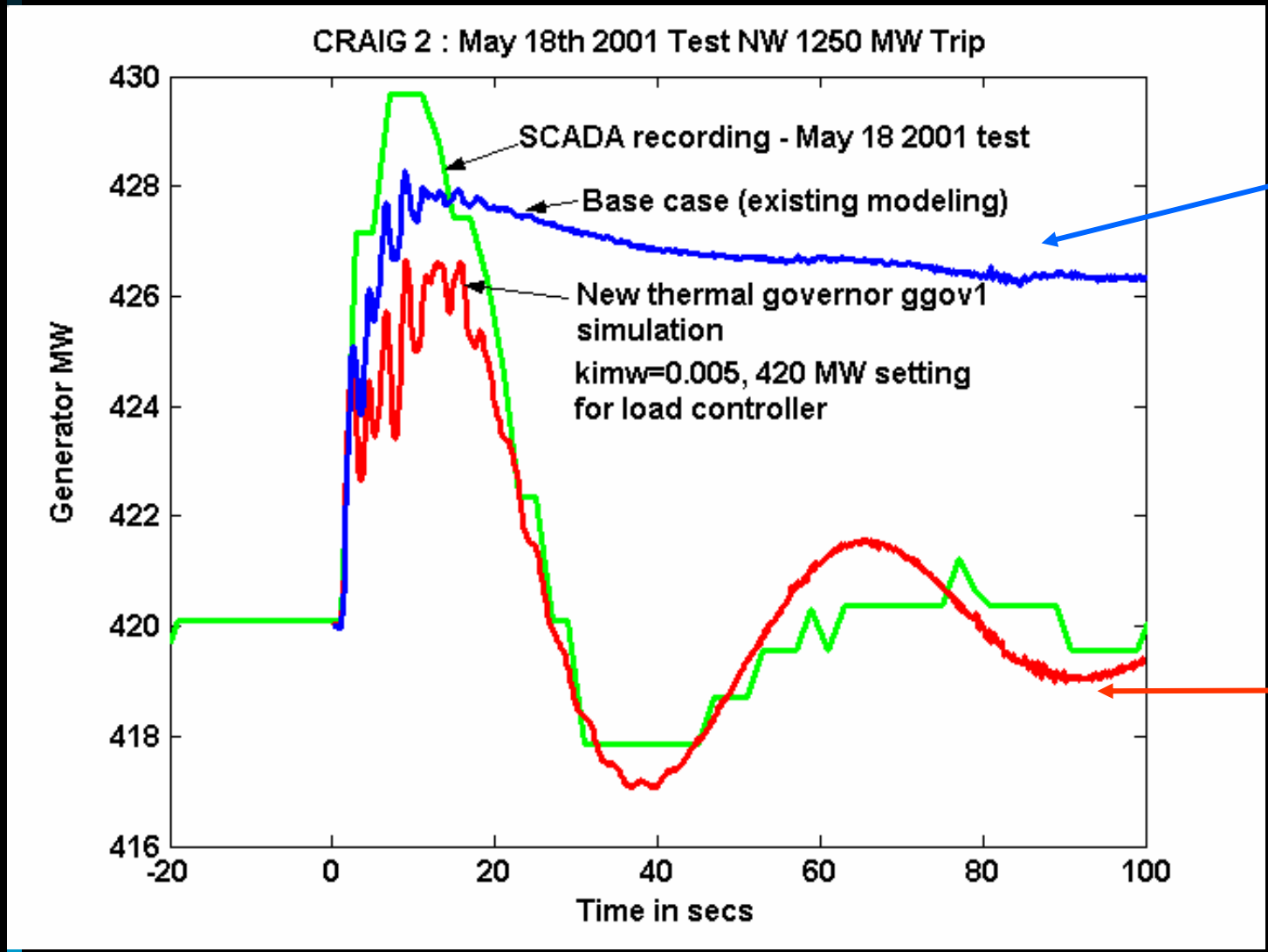
Typical “Base Loaded” Generator



Inaccurate Existing Model

More Accura New Therma Governor modeling

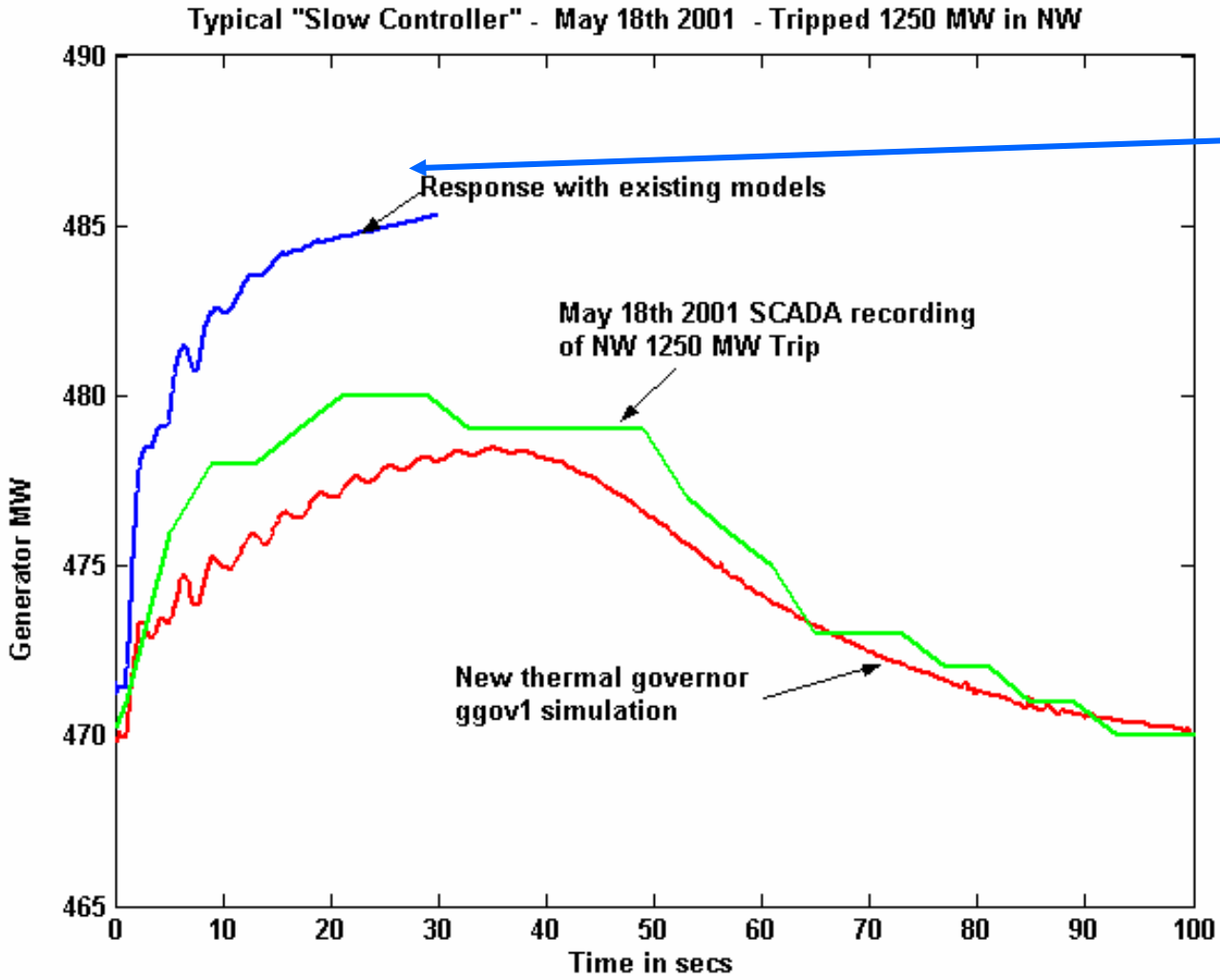
Typical “Fast” Load Controller Model



Inaccurate Existing Model

Accurate new modeling

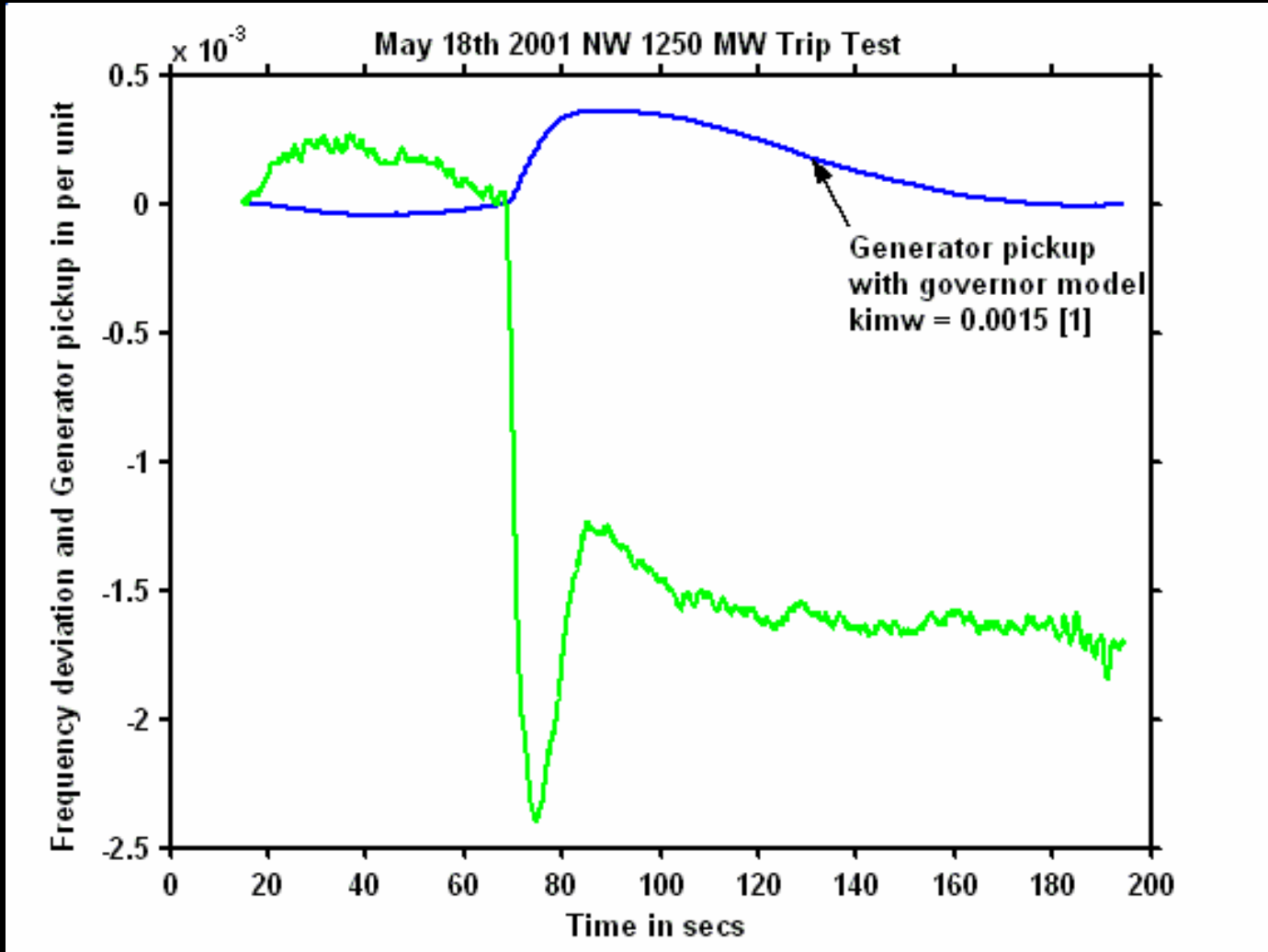
Typical “Slow” Load Controller Model



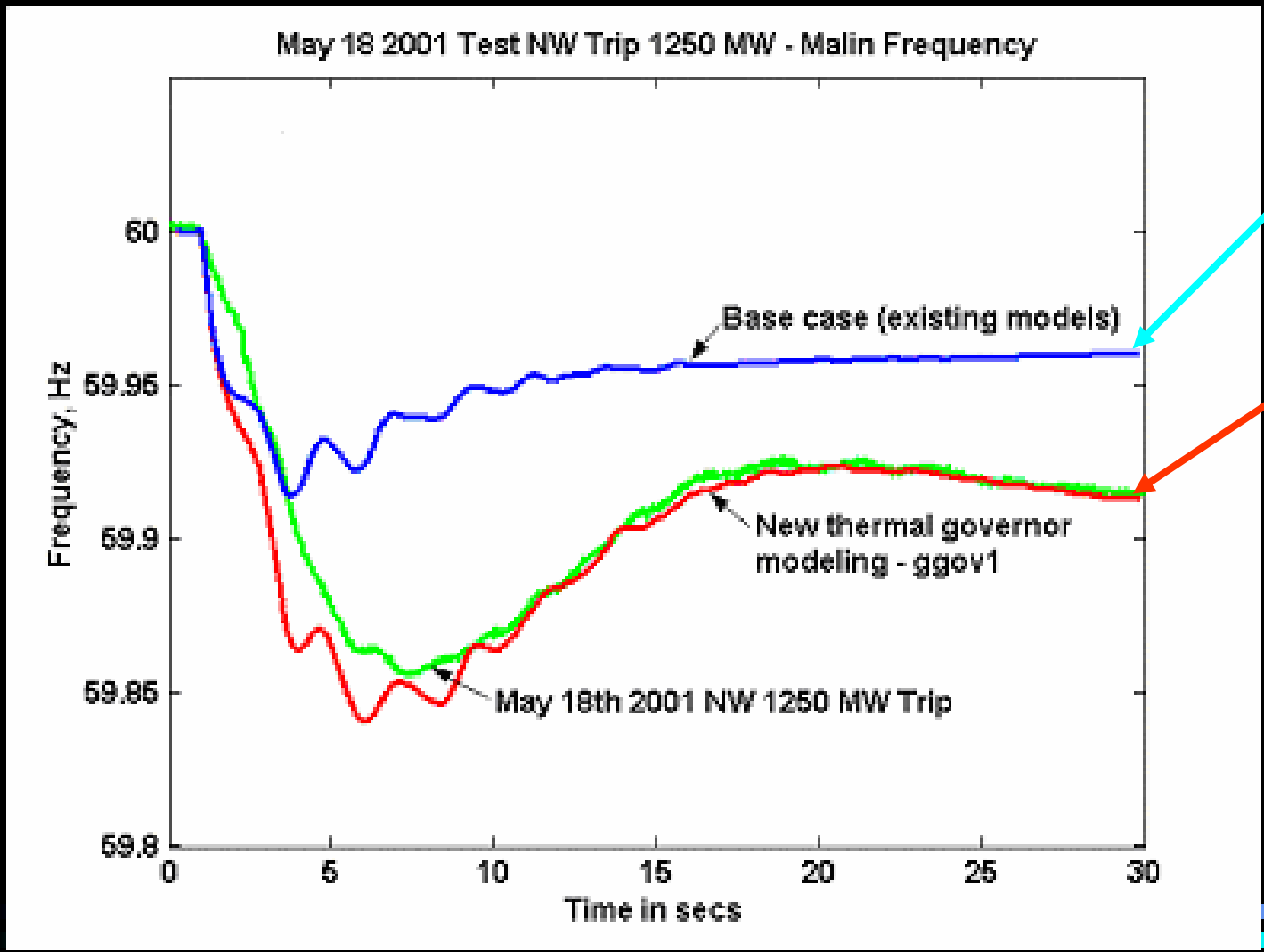
Inaccurate Existing Model

Accurate new modeling

Eg. Kimw=0.0015 - 'slow' controller- vs Frequency



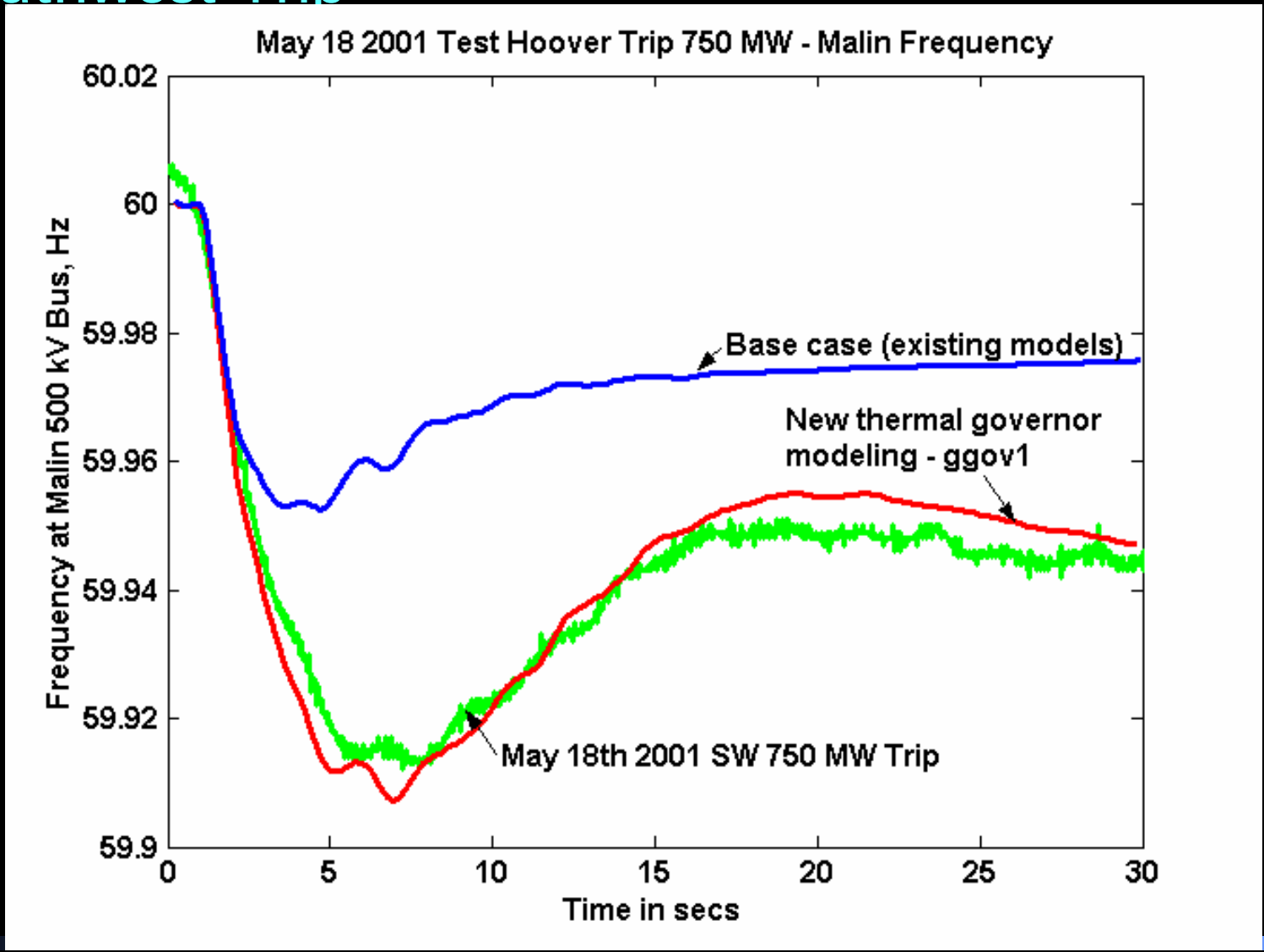
May 18th frequency response to 1250 MW Northwest Trip



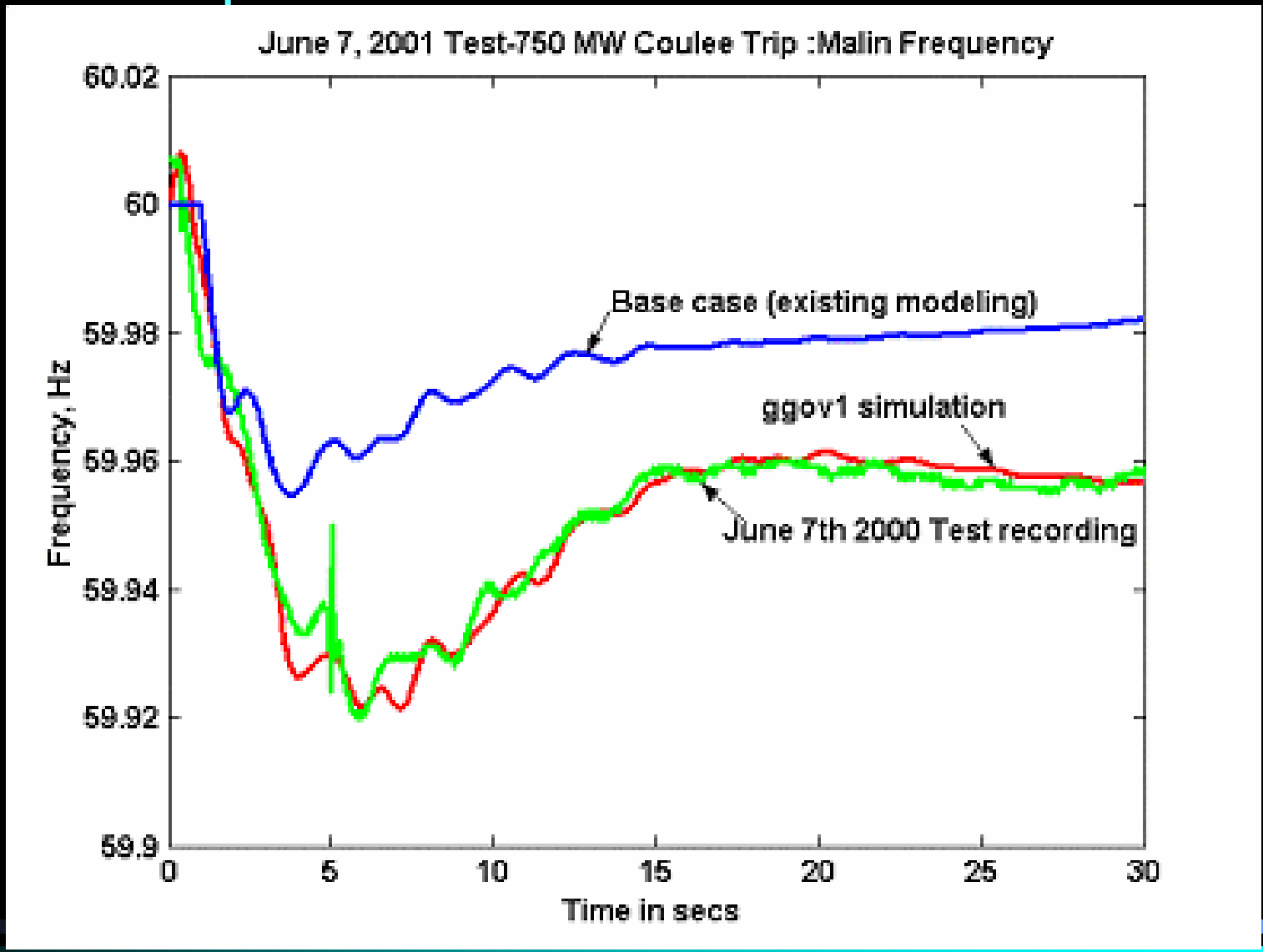
Inaccurate Existing Model

More Accurate New Thermal Governor modeling

May 18th frequency response to 750 MW Southwest Trip



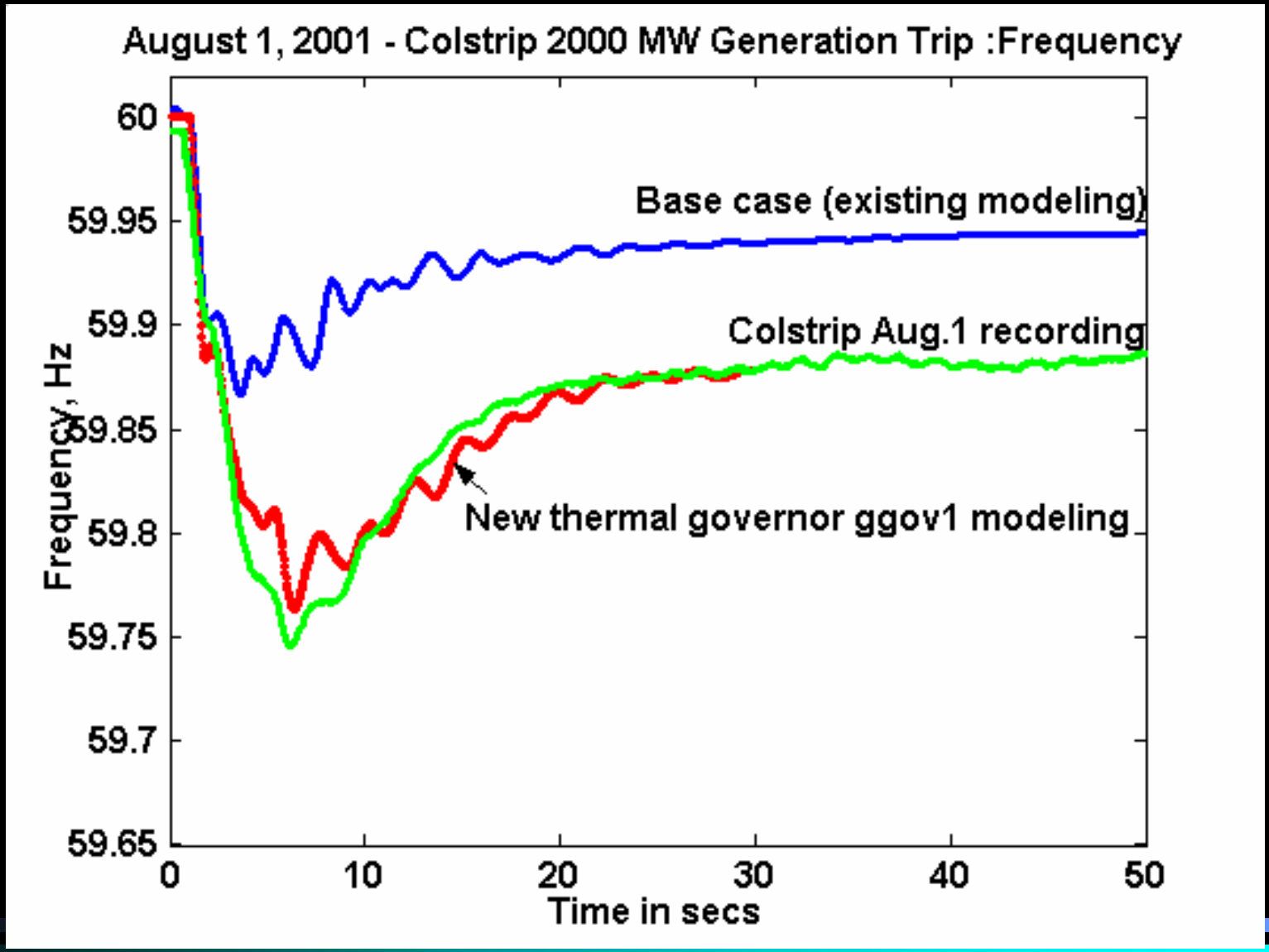
Validation response to June 7th 2000 750 MW Coulee Trip – with the "New" model



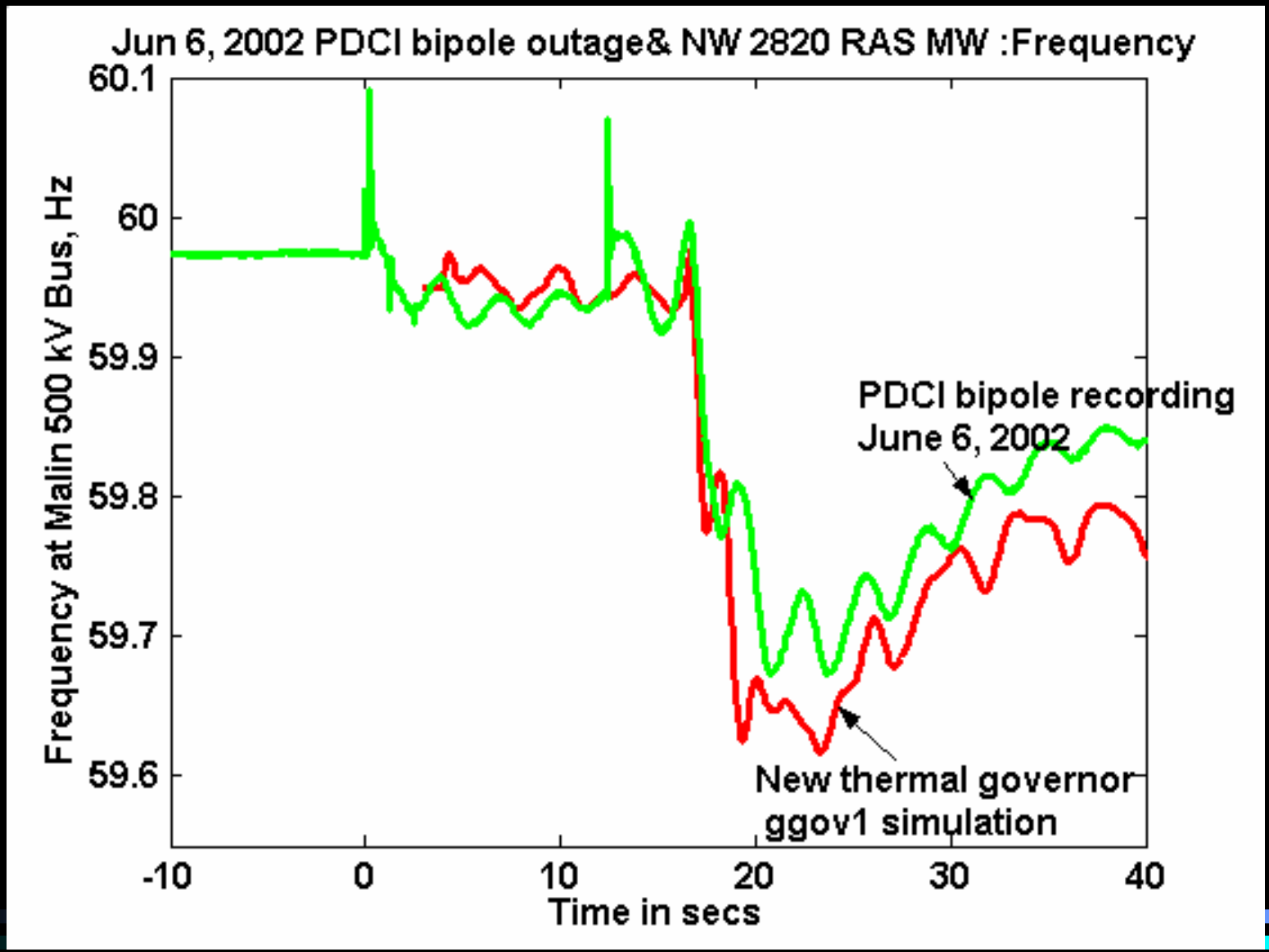
Some “Verification” runs - random events

- Verification –
  - Colstrip 2000 MW trip, Aug.1, 2001
  - Diablo Jun3, 2002 – 750 MW trip
  - PDCI bipole + NW RAS : Jun 6, 2002

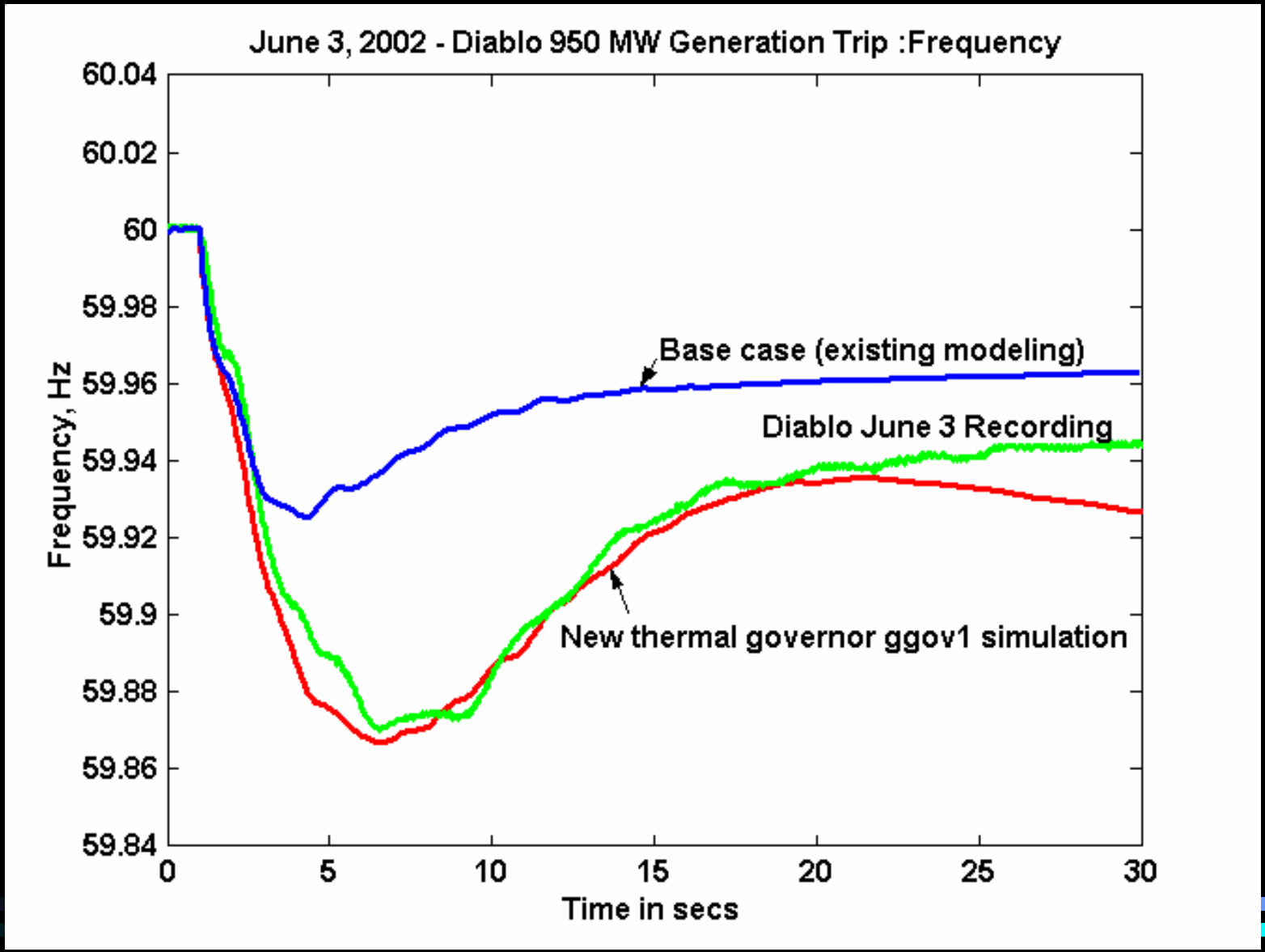
Verification – Aug.1 Colstrip 2000 MW trip



Verification – June 6th 2820 MW PDCI trip



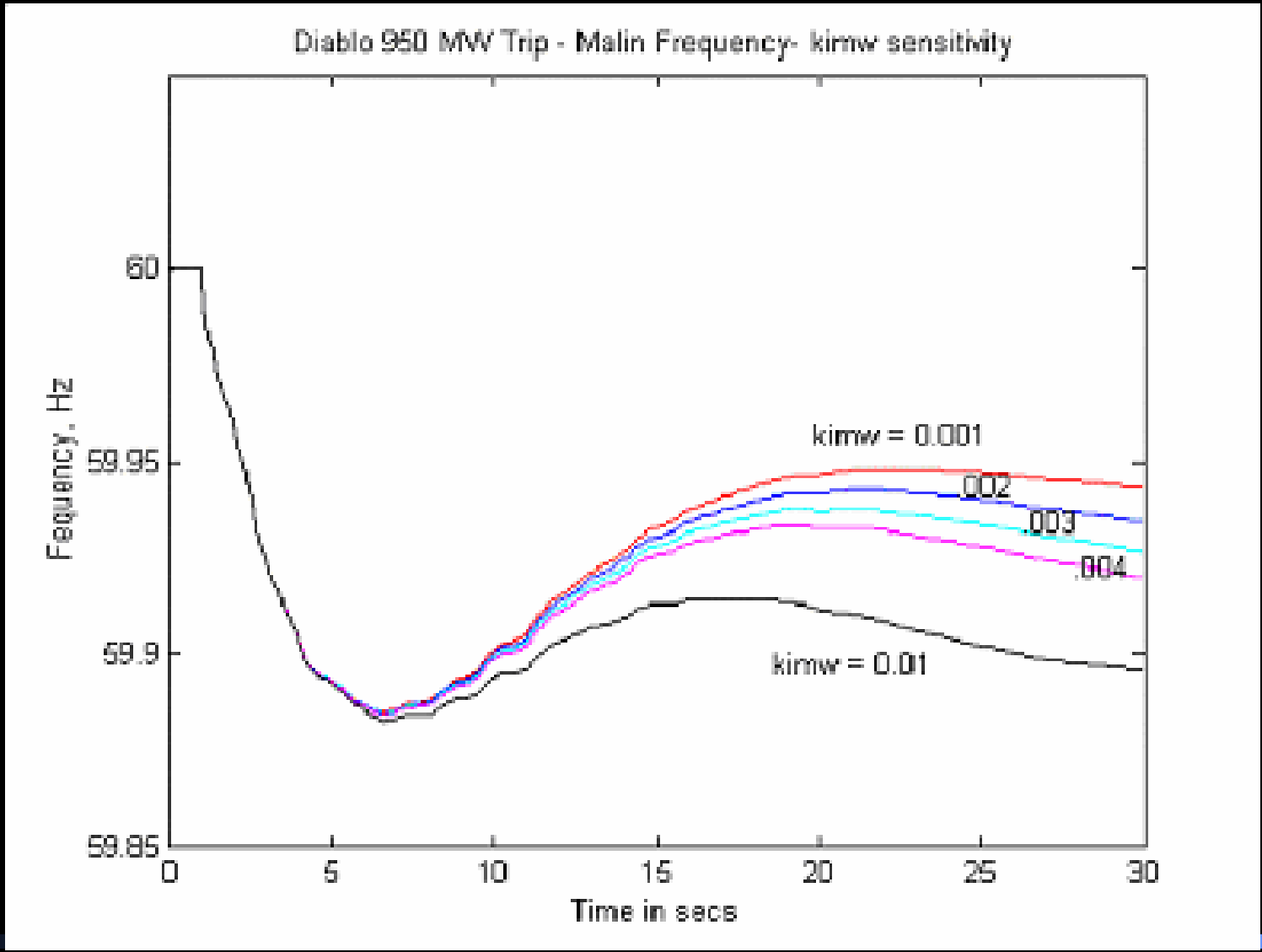
Verification – June 3 Diablo 950 MW trip



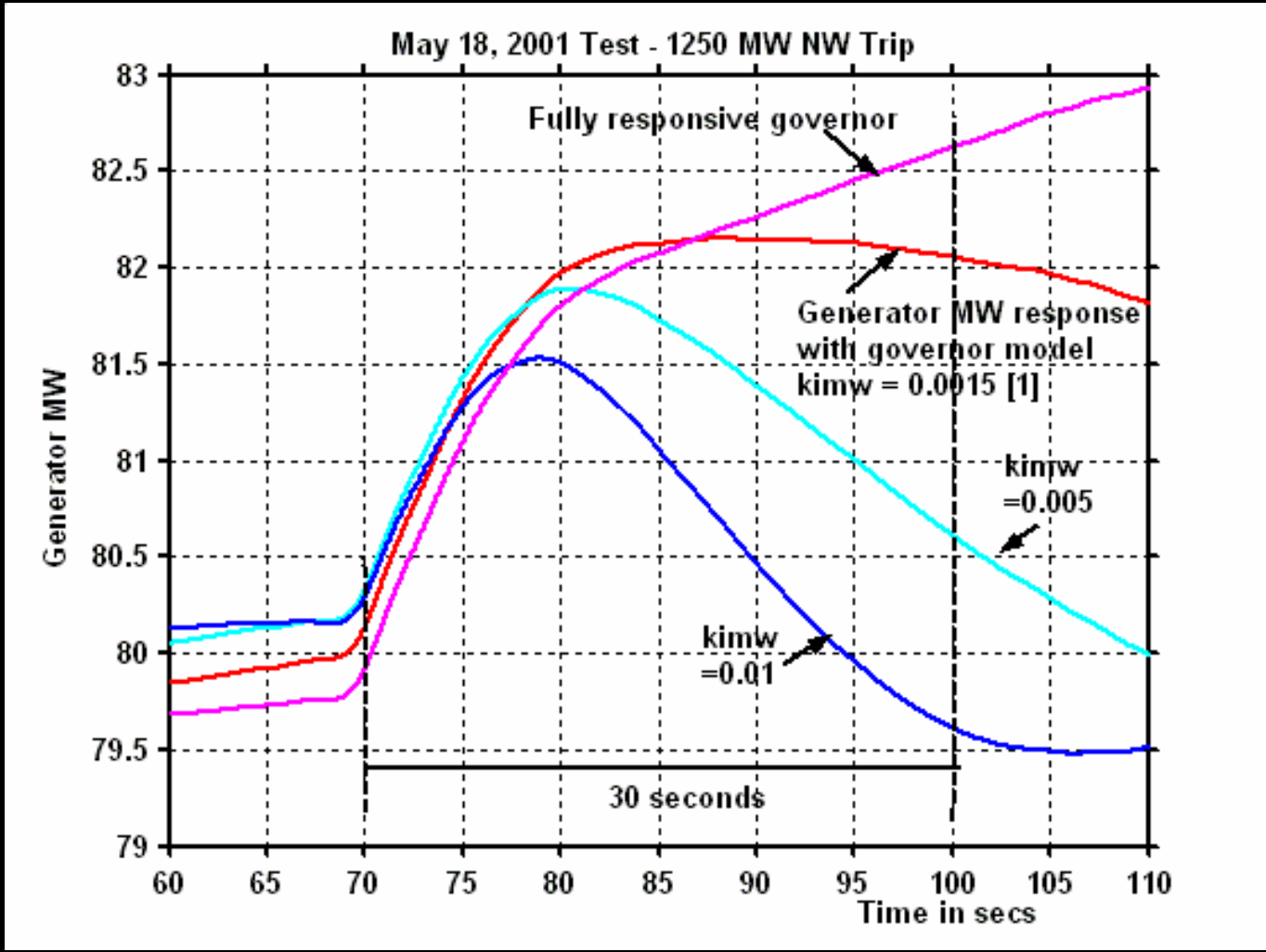
Sensitivity Studies

- Governor parameters
  - “Fast” and “Slow” controller parameter “kimw”
  - PID parameters
- Turbine parameters, Tb and Tc

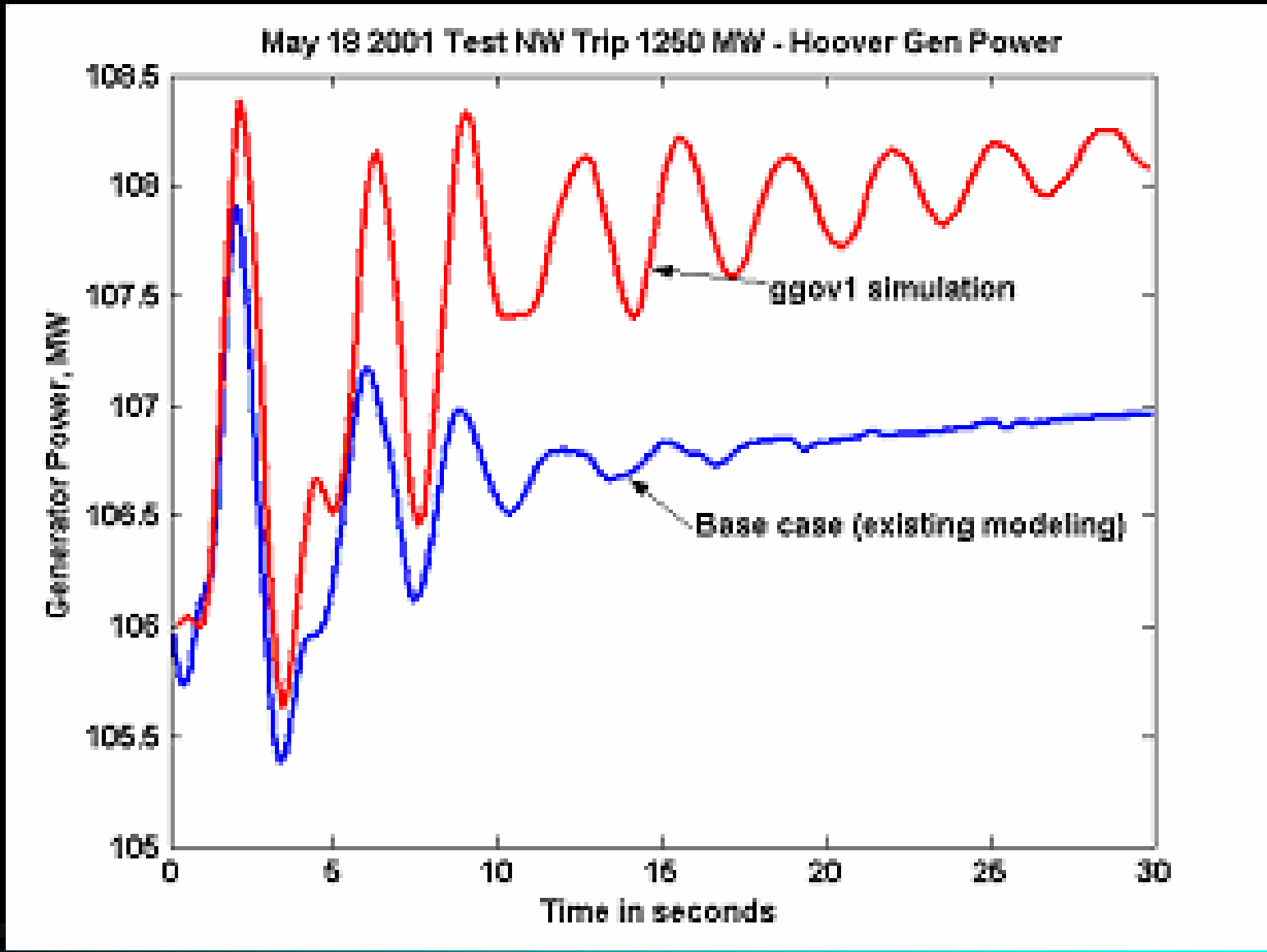
Kimw sensitivity on System Frequency



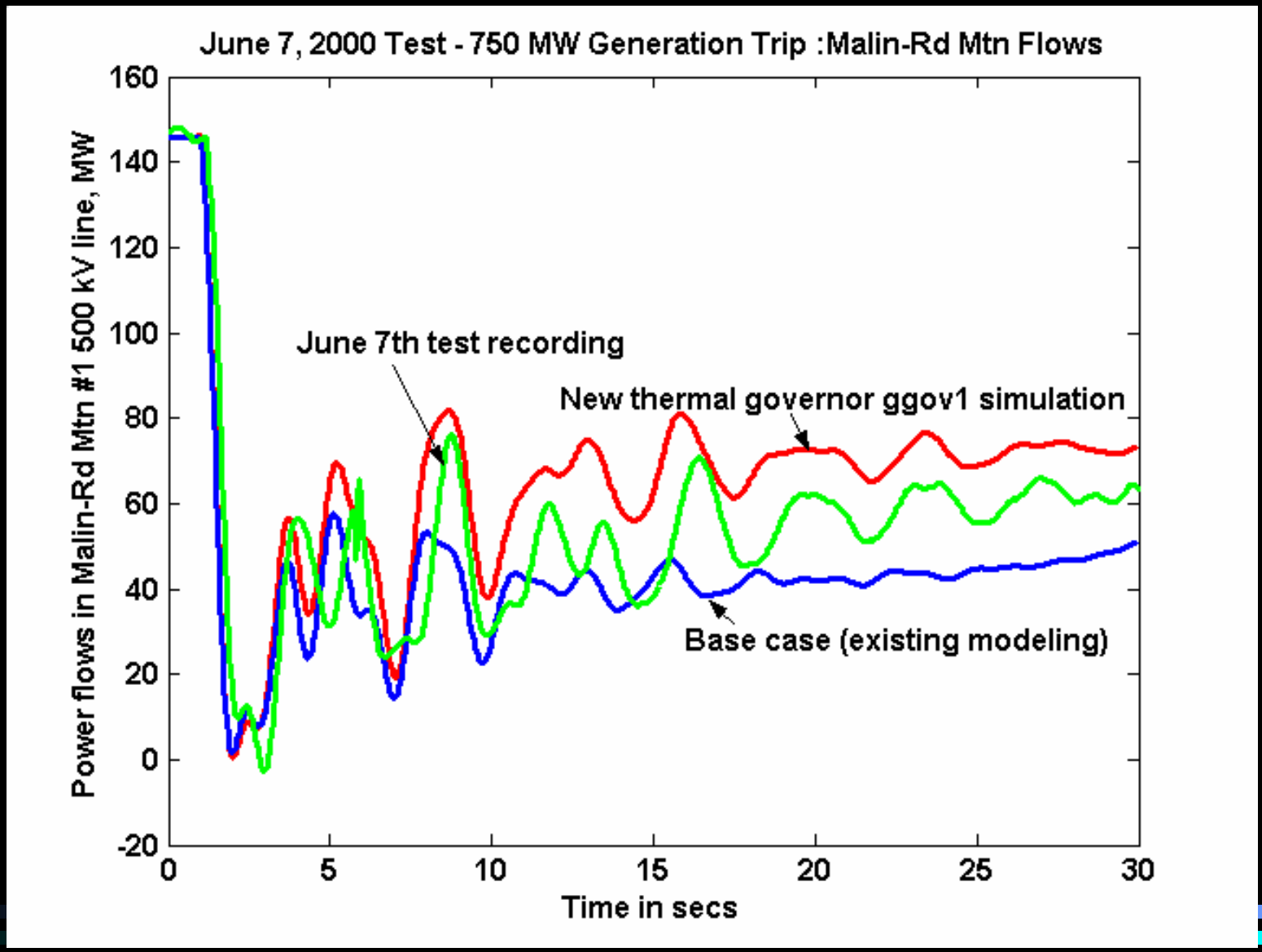
Kimw sensitivities – model selection



Effect on Hydro power response

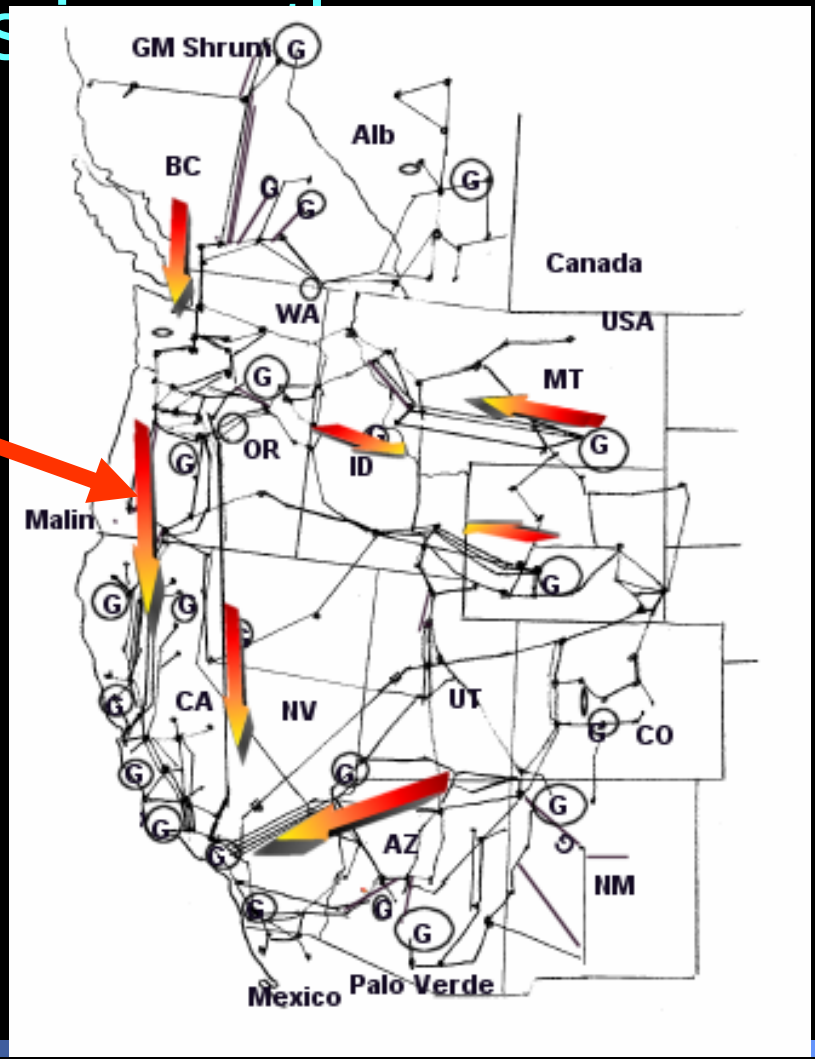


COI flows – June 7th test - oscillations

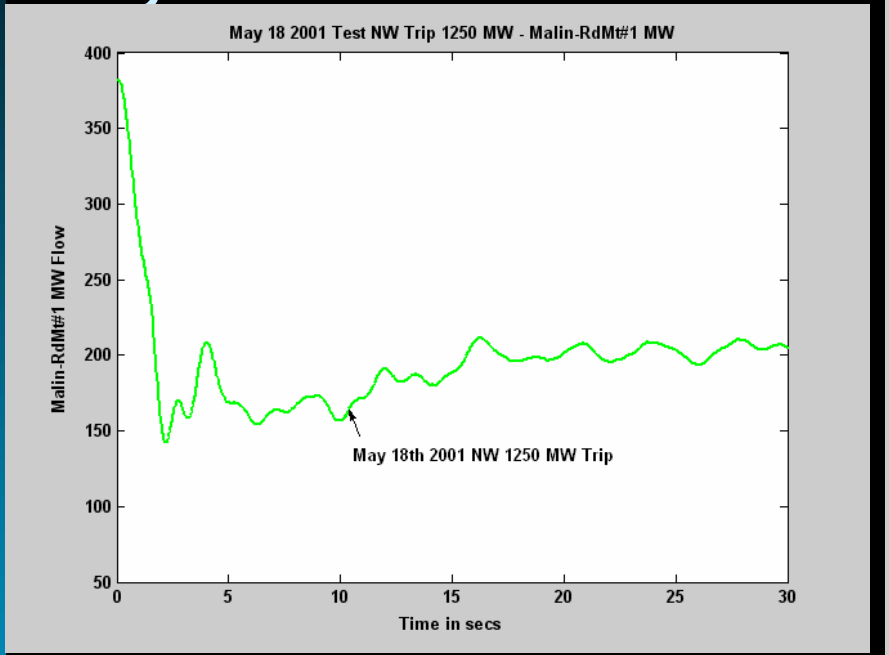


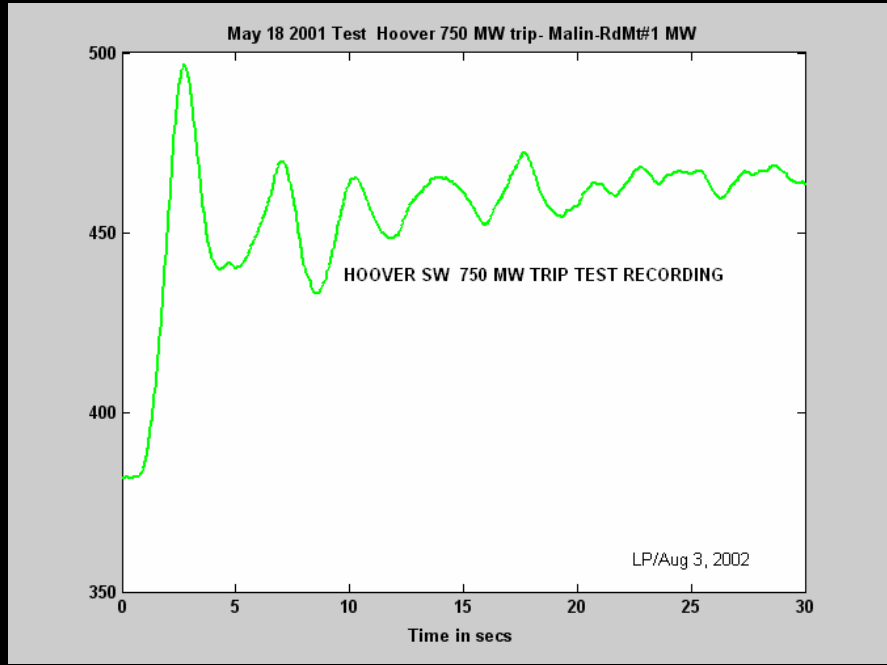
The 3-Line 4800 MW COI Intertie plays a major role in the response between hydro in NW and thermals

COI - Intertie



COI Flows for Gen Trips in NW & SW
May 18th 1250 MW test





Trip in NW –
COI Flow N-S drops

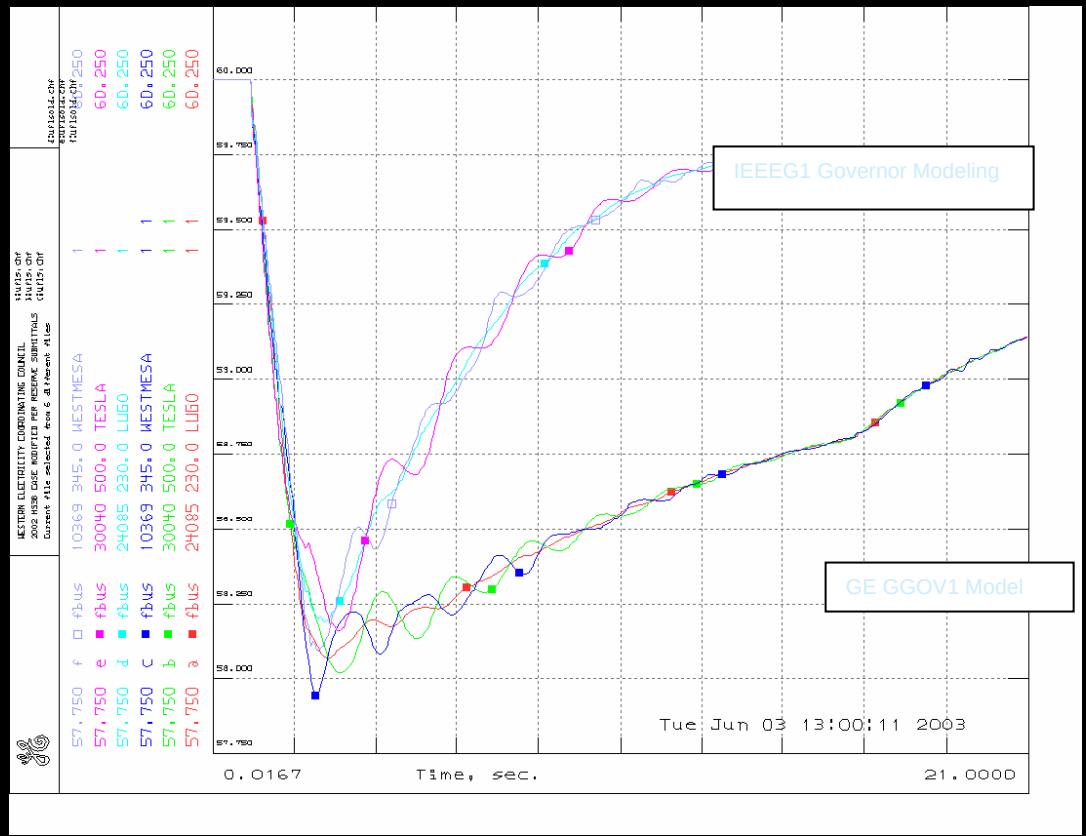
Trip in SW –
COI Flow N-S picks-up.
For large SW trips, COI overloads

Impacts and related issues

- Accurate thermal governor modeling effects hydro governor responses
- Improved pickup of generators system wide improves overall system simulations
- More accurate COI pickup – OTC limits
- Provides a methodology for more accurate post-transient powerflow studies
- Other studies – UFLS
- New FRR standards in WECC defines spinning reserves requirements more accurately

UFLS Studies: Old models versus New Thermal Governor Models ggov1

- System recovery is slower with the new governor modeling



Validation with Generator Owner's Data

Principles, policy

- The ‘developmental’ database that was created to prove the new thermal governor model should not be used to perform operation or planning studies, or in the determination of intertie limits

- Owner is responsible for providing data for its governor models that simulates its generator responses for system frequency deviations

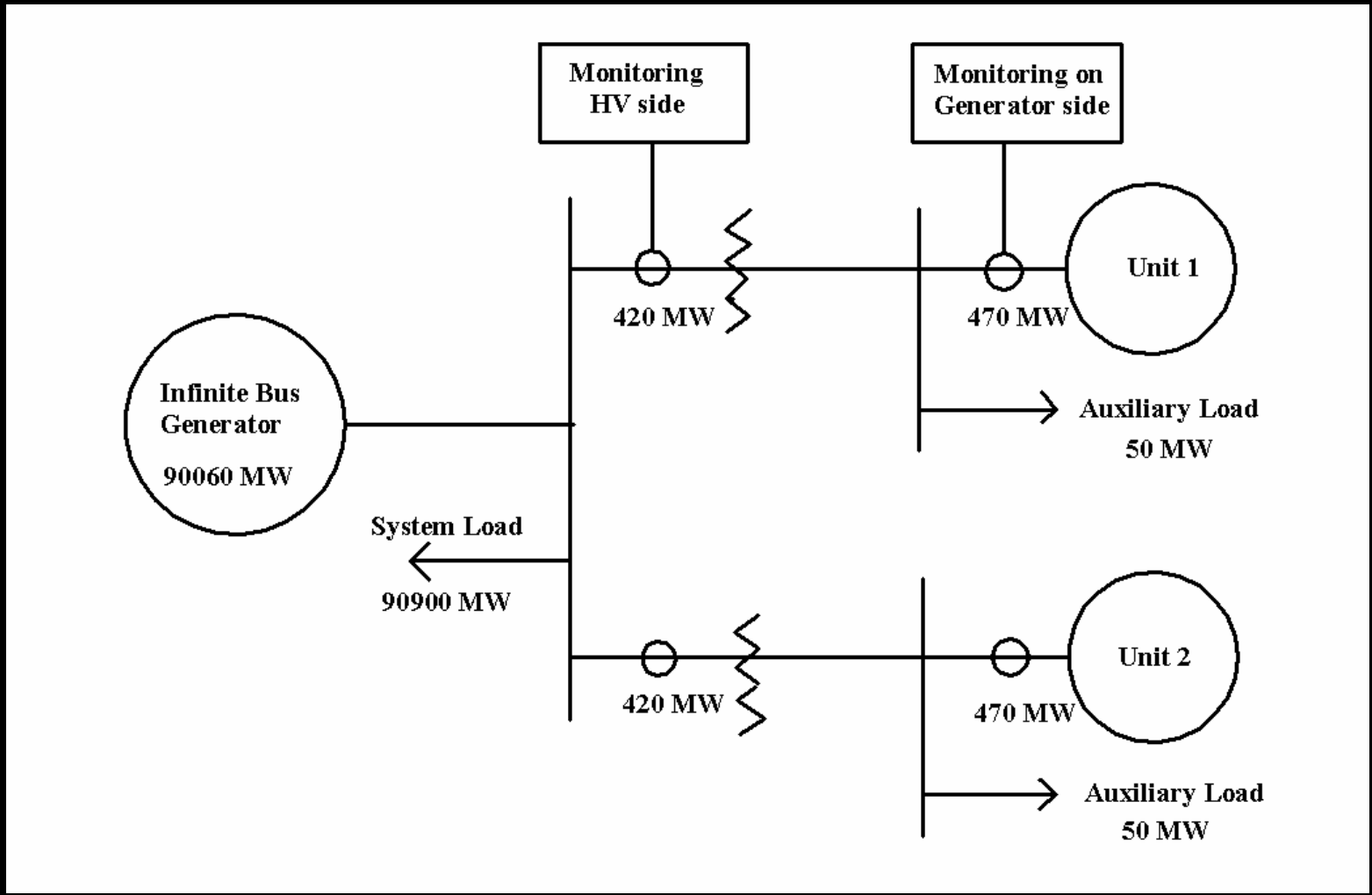
Workshop, Guidelines, Tools

- Workshop & several meetings
- Issued detailed Guidelines for Selection & Validation
- Issued Validation Simulation Tools

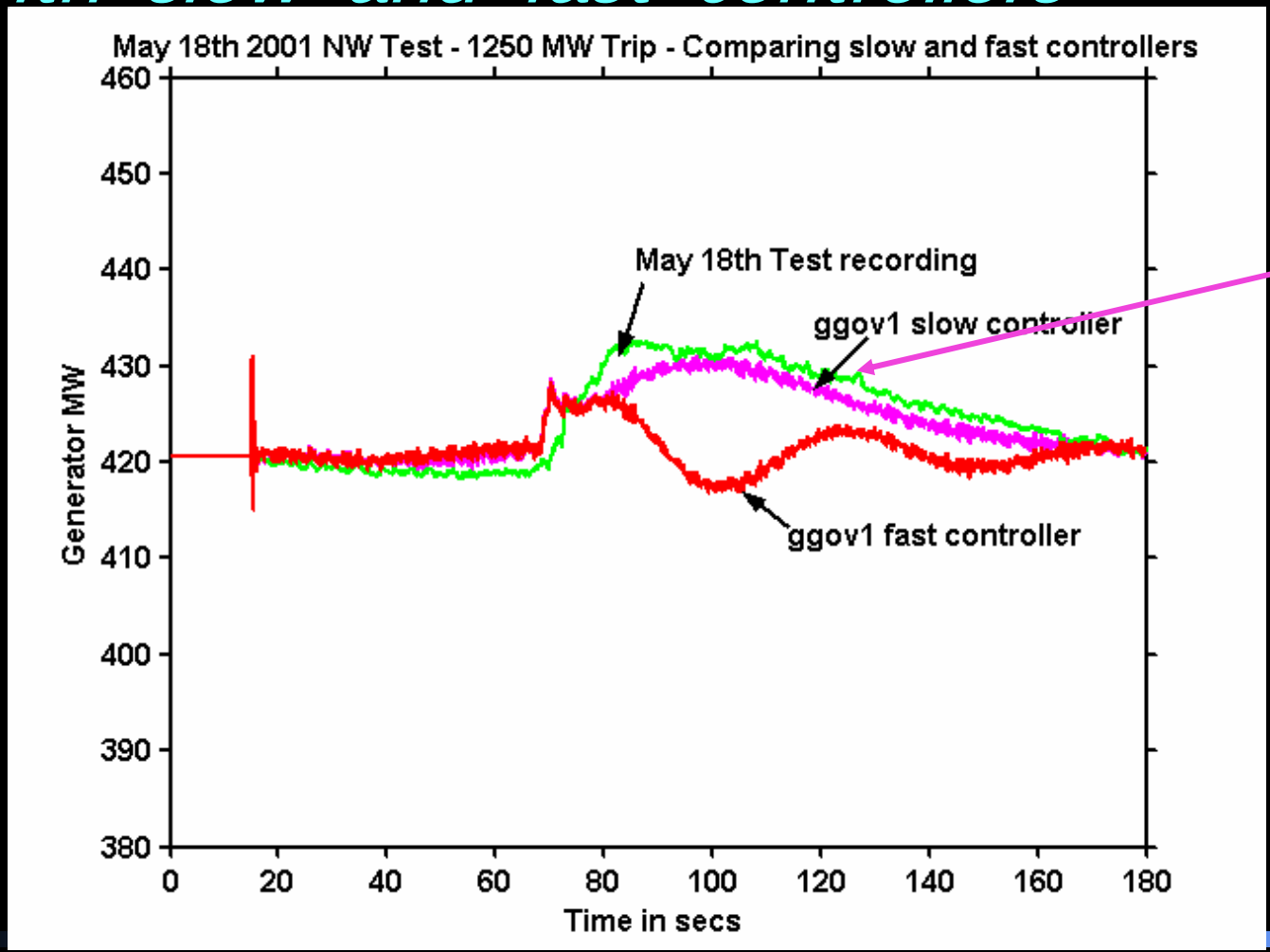
‘New’ Models added in the governor validation effort

- 400 ‘new’ models added
- Ieeeg1 thermal models were kept the same, simply added load controller models, lfcb1
- 50 ‘new’ hydro models added
- 100 ‘new’ exciter models

Simulation and Model Validation using a Small Equivalent System



Simulation and Model Validation using a Small Equivalent System with 2 generators with 'slow' and 'fast' controllers



Select the 'Slow' Controller Model - It has the better fit

Simulation and Model Validation using a Small Equivalent System

We supplied all Owners with frequency recordings for the following real WECC Events :

1. July 27,2002 (19:19 PDT) 4 Corners trip (2065 MW)
2. July 15,2002 (13:04 PDT) NW RAS trip (2350 MW)
3. July 16,2002 (15:41 PDT) NW RAS trip (2350MW)
4. June 6, 2002 (13:47 PDT) PDCI loss (2800 MW)
5. Oct.8, 2002 (15:31 PDT) NW RAS trip (2900 MW)

More recent data will be posted as required for validation.

A recent validation - June 14th 2004

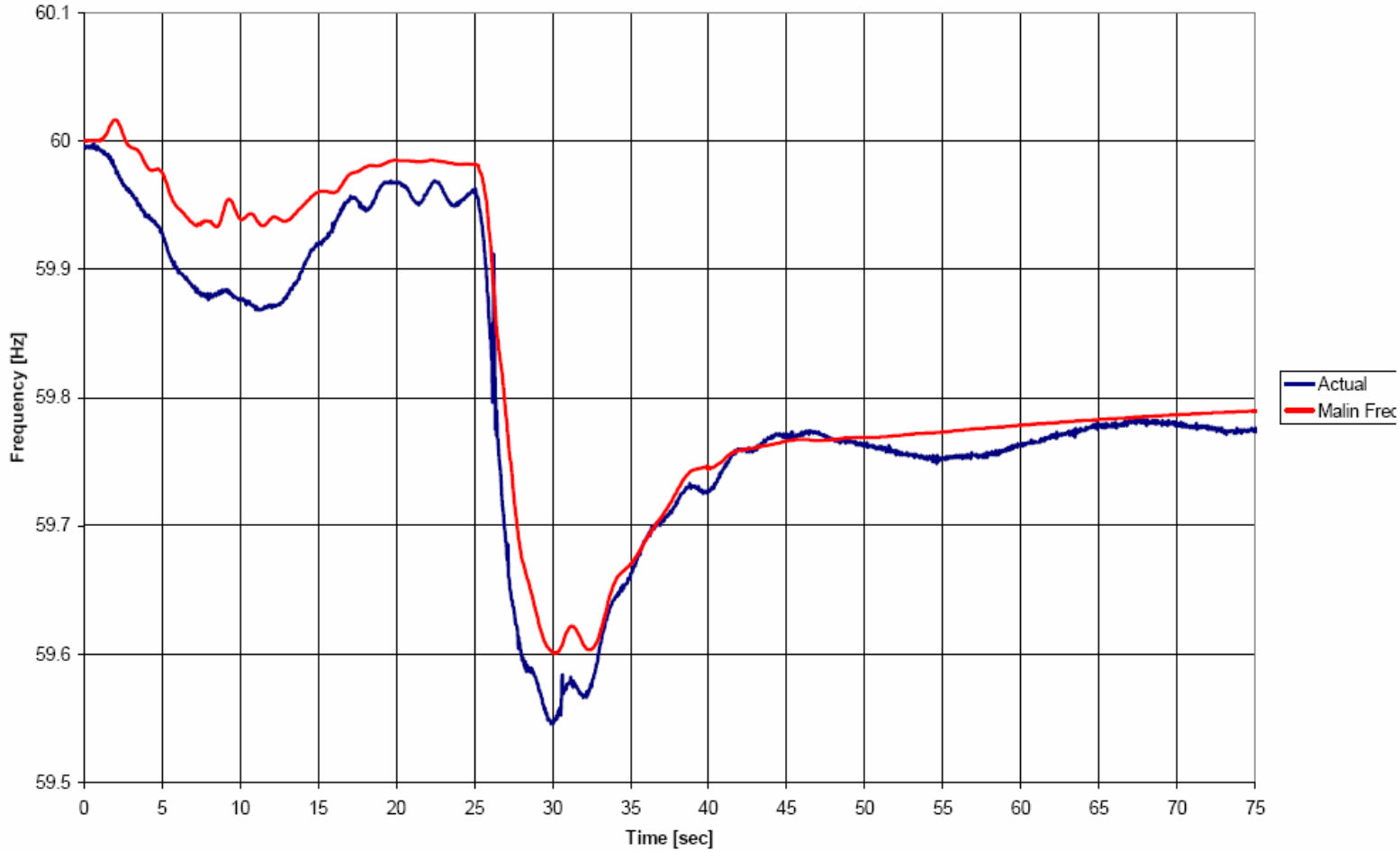


Figure 1: Comparison of simulated and actual frequency at Malin 500 kV before model adjustments

June 14th 2004 validation – Malin kV

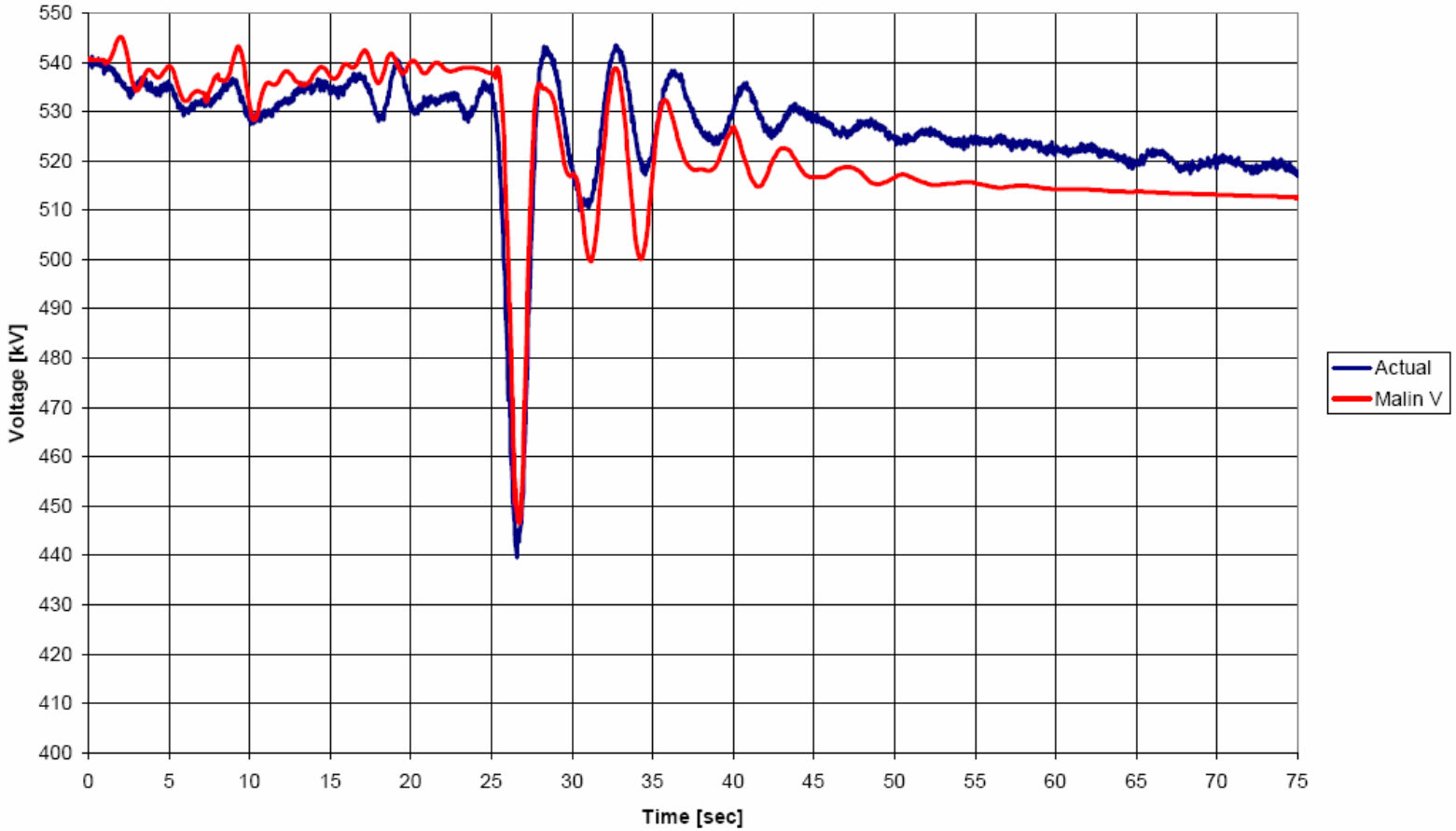


Figure 4b: Comparison of simulated and actual Malin 500 kV voltage after model adjustments

June 14th 2004 validation – COI MW

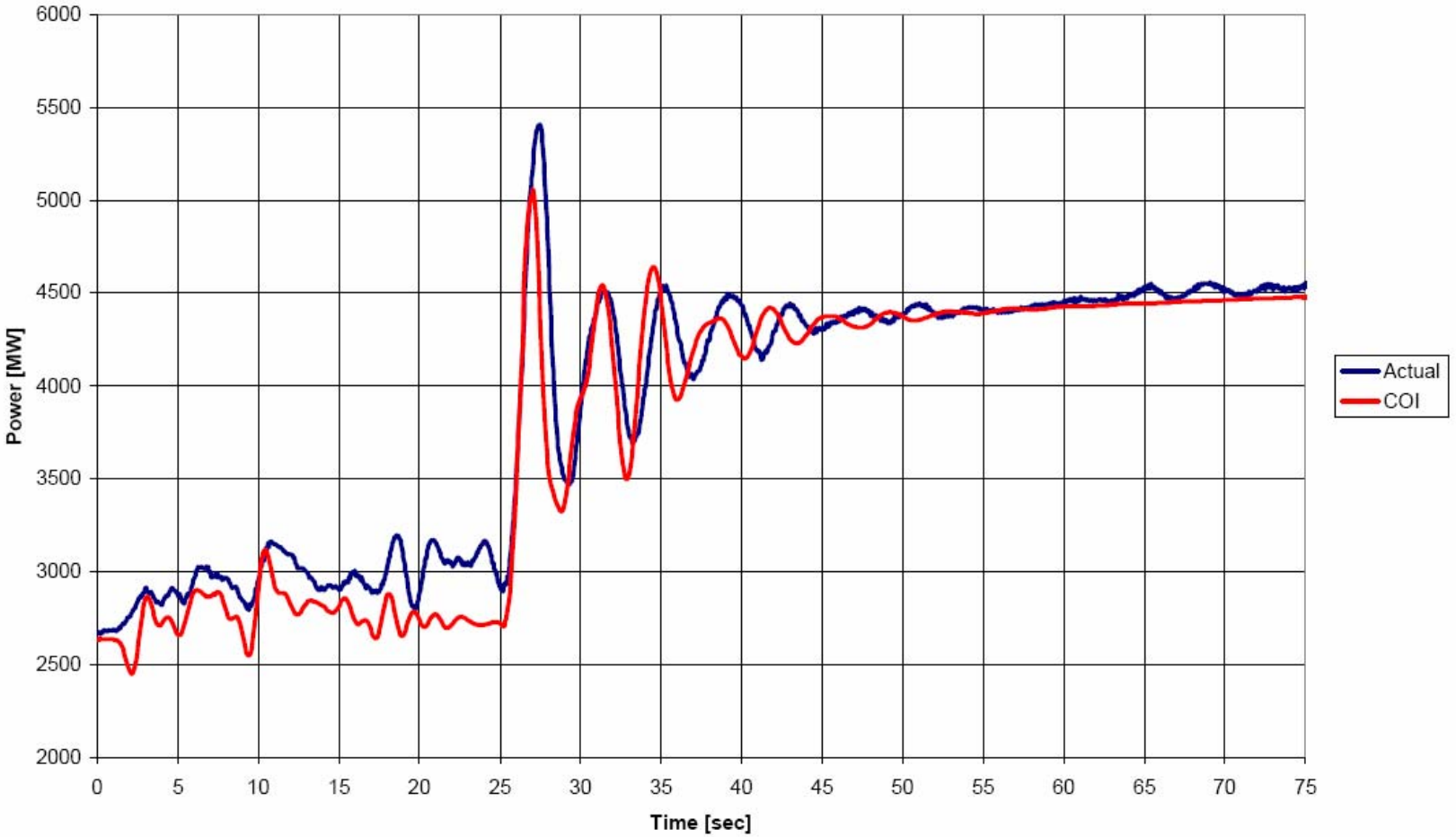


Figure 4c: Comparison of simulated and actual COI real power transfer after the model adjustments

Guidelines and Tools for Governor Validation on Web site

http://www.wecc.biz/modules.php?op=modload&name=Downloads&file=index&req=viewsdownload&sid=52

Zip File with PSLF input files for Example 1 of the Guidelines

Description: PSLF input files. 11 documents in a zipped folder.

These files still work well but additional files will be posted with new updates with the latest GE PSLF program's "playback" Feature which is easier to use.

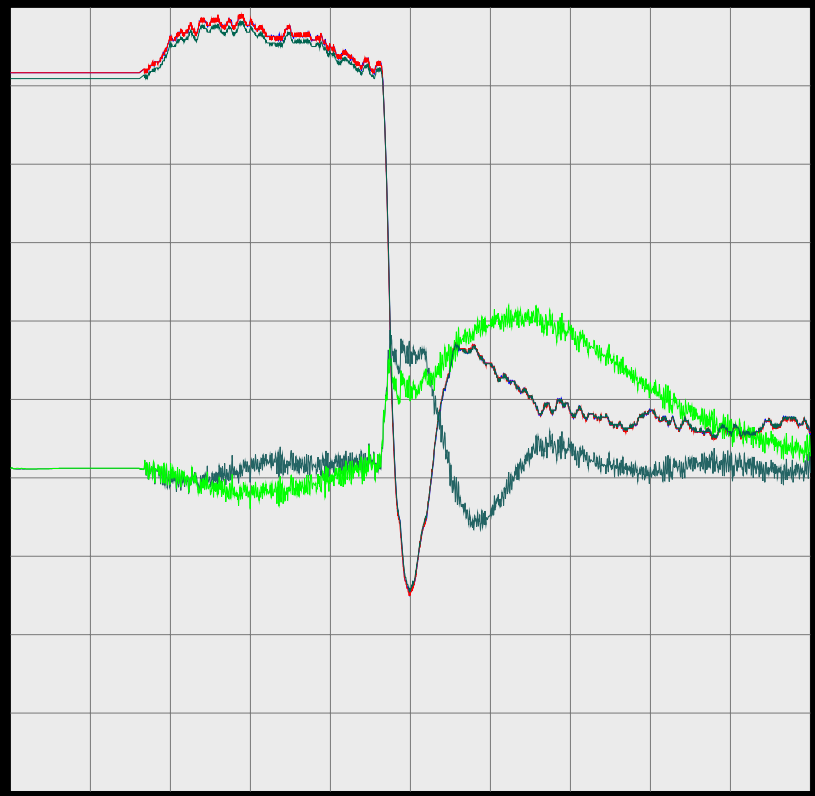
To be posted:

- Unitxy_2.sav file
- Unitxy_2.dyd file
- e010518.csv file
- runUnitxy.p epcl file

gencls is the ‘playback’ generator in dyd:

```
gencls   12357 "INFINITE" 500.00 "1 " : #9 mva=1250000.0
4.0   0.0   0.0   0.2   99.   99.  15.  e010518.csv
```

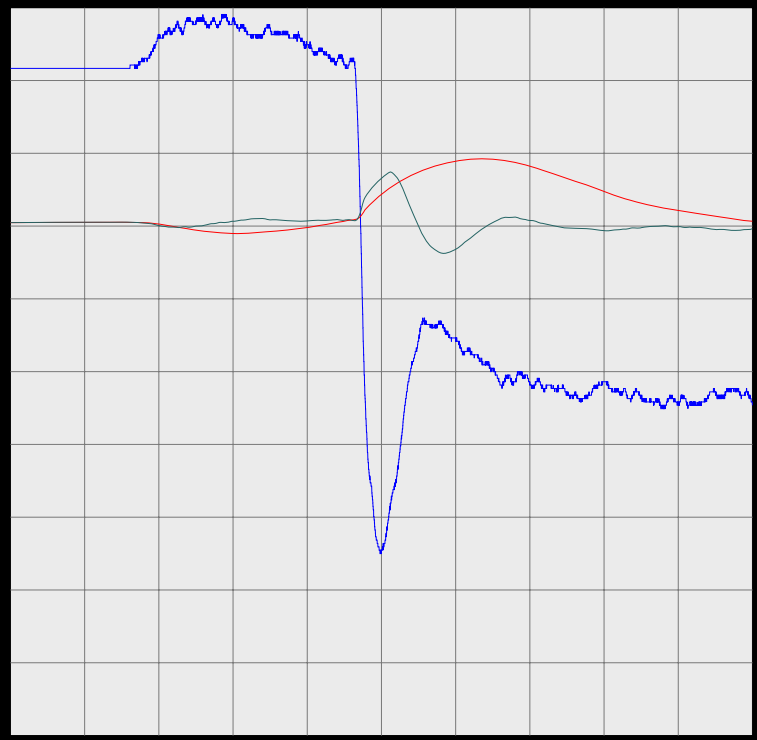
GE PSLF program's "playback" Feature



0.9967	spd	12348	UNITYY 3	26.0	1	1	1.0003
0.9967	spd	12357	INFINITE	500.0	1	1	1.0003
400.0	pbr	3	UNITYY 3	500.0	1	1	450.0
400.0	pbr	4	UNITXX 4	500.0	1	1	450.0
59.8	fbus	3	UNITYY 3	500.0	1	1	60.02

UNITXX YY

GOVERNOR RESPONSE VALIDATION



0.9967	a1	12357	INFINITE	500.0	1	1	1.0003
400.0	pm	12347	UNITXX 4	26.0	1	1	500.0
400.0	ph	12348	UNITYY 3	26.0	1	1	500.0

Spinning Reserves

- Currently the expected response after generation trips based on spinning reserves is overestimated
- New Frequency Response Reserves (FRR) Standards are being formulated which will be more precise. It will change the concept of ‘spinning’ reserves as we know it now

Governor Modeling FAQ

- What is the importance of modeling frequency accurately?
- Why do we ‘block’ governors from operating after modeling it in great detail?
- Why do NERC/WECC standards still require 5% droop governors when many governors are not operated as such?
- How will the new FRR standards affect governor operation and modeling?
- What’s going on in the Eastern Interconnection regarding governor modeling?

FRR

Frequency Responsive Reserve (FRR) Obligation for the Western Interconnection.

- That amount required to respond to the simultaneous loss of the two largest generators* in the Western Interconnection or the amount determined by studies for the prior year as approved by the WECC Operating Committee.

* 3200 MW - ref white paper

Required FRR Response.

- The Required FRR Response shall be the automatic deployment within 30 seconds after the start of the event for frequency deviations greater than or equal to 0.25 Hz.
- For frequency deviations less than 0.25 Hz the

(scheduled frequency [**Fs**] minus actual frequency [**Fa**]) multiplied by the FRR Allocation divided by 0.25 Hz.

Required FRR Response

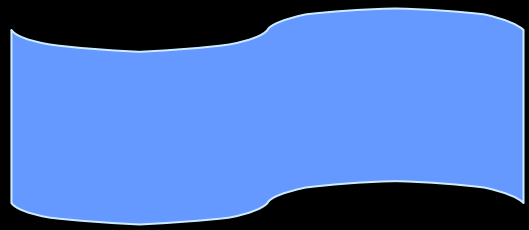
$$= \frac{(Fs - Fa) * \text{FRR Allocation}}{0.25 \text{ Hz}}$$

FRR will include the action of AGC for pickup

AGC modeling

- Should AGC be modeled?
- Some owners have designated certain governors as frequency “responsive” : but these were really AGC units
- To create effective AGC modeling requires a lot of response data, system-wide, after a generation trip.
- Selection of AGC units in each CA is from a pool and will vary. The selection criteria could change after new FRR standards.

Some recent generation trips



Post-Transient Powerflow Studies

- The new modeling principles are used in all current post-transient or ‘governor’ powerflow studies in the WECC
- Block the pickup of generators that are ‘base-loaded’ in the powerflow cases.
- Also block fast controllers for more conservative studies.

Thank you!